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FROM

Lawrence S. Mayo

Board of Education, South Kensington.

CATALOGUE

OF THE

MECHANICAL ENGINEERING COLLECTION

IN THE

SCIENCE DIVISION

OF THE

VICTORIA AND ALBERT MUSEUM,

SOUTH KENSINGTON.

WITH DESCRIPTIVE AND HISTORICAL NOTES.

PART I.

STEAM ENGINES AND OTHER MOTORS;
LOCOMOTIVES AND RAILWAYS;
DYNAMOS AND ELECTRICAL FITTINGS;
MECHANICAL MEASURING APPLIANCES;
PUMPS AND LIFTING MACHINERY;
POWER TRANSMISSION.

Fourth Edition, with a Supplement containing illustrations.

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PREFACE.

THIS Collection was commenced in 1867, by direction of the Lords of the Committee of Council on Education, with the view of affording in the best possible manner information and instruction on the immense variety of machinery in use in the manufactures of this country, and by the employment of which the commerce of the nation has been rapidly extended for many years past. A most valuable addition, consisting of models made by James Watt himself or his workmen, was in 1876 presented to the Museum by Messrs. James Watt & Co. A further large accession of machines and models was received from the Patent Office Museum when, in 1884, it ceased to be continued as an independent collection, and its contents were handed over to the Science and Art Department, now merged in the Board of Education. From time to time purchases of particularly interesting objects have been made, but to a very large extent the Collection has been assisted by presents and loans of machinery, models, and drawings, from manufacturers and inventors, and it must always rely mainly upon such sources for its augmentation.

It is not the object of the Collection to attempt, nor is space available, to indicate the present state of the arts in any one particular branch of engineering, but rather to illustrate broadly the steps by which advances have been made up to the present day; to show students and others at the same time the general principles which underlie all its branches and to offer to the engineer suggestions or ideas from other branches of his profession for improvements in the work on which he may be engaged.

Many of the machines are shown in motion daily from 11 a.m. till closing time, the motive power being supplied by a compressed air service. Where practicable, these working models are fitted with self-closing air-valves, by means of which visitors may start them at will, notices to this effect being placed with the models so fitted.

The more important objects in the Mechanical Engineering Collection have been photographed. These photographs may be ordered at the Sale Stall, Victoria and Albert Museum, or by letter addressed to "The Secretary, Board of Education, South Kensington, S.W."

*** *In the Science Library of the Victoria and Albert Museum is a complete series of Specifications of the Patent Office, from* 1617 *onward, which may be consulted free.*

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CONTENTS.

(The objects in the various sections are arranged chronologically.)

CATALOGUE

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PART I.

When a reference is made in the text, it is to the serial numbers at the beginning of each entry. When an object is illustrated the reference is given immediately after the entry. The numbers in the right hand lower corner are those under which the objects are registered in the Museum, and the dates given are those when the objects were first received.

STATIONARY STEAM ENGINES.

The earliest known record of the employment of steam as a motive agent is that of Hero of Alexandria, a philosophical writer who flourished, it is believed, about 150 B.C. He left several treatises on mechanical subjects which are interesting as records of the knowledge of his time; of these, the best known is his compilation on "Pneumatics," in which he describes the *æolipile*, or reaction steam engine, and a steam jet supporting a light ball (*see* No. 1); the first of these was occasionally used practically during succeeding centuries, but was never more than a toy owing to its inefficiency. A few proposals for using high pressure steam that bore fruit much later are met with in philosophical writings up to the middle of the seventeenth century (*see* Nos. 2 and 3).

It was at this time, however, that the important discovery was made that the atmosphere was a fluid possessed of weight, the pressure due to which could be excluded at will from the interior of a closed vessel so as to obtain a vacuum (*see* No. 4), facts destined to have a most important bearing on the development of the steam engine. The means for obtaining this vacuum were found in the adaptation for the purpose of the common syringe or the bucket pump. The properties of the air pump and the experiments that could be made with it became widely known, but it was some years before it was realised that the converse action was also true, *i.e.*, that if a vacuum could be obtained readily below the bucket or piston, then the pressure of the atmosphere could be utilised for doing mechanical work. Acting on this idea, Huyghens in 1678-9 exploded a charge of gunpowder in the bottom of a vertical cylinder. The greater part of the air and of the gaseous products were expelled through non-return valves; the cooling of the remaining gases produced a partial vacuum below a piston which then descended owing to atmospheric pressure, doing work by means of a cord over a pulley. Papin, in 1690, demonstrated the suitability of steam for producing the vacuum (*see* No. 6), but was no nearer solving the problem of how to repeat at frequent intervals this reciprocating motion by causing differences in pressure behind the piston.

In the meantime the idea of raising water by the direct pressure of steam upon its surface in a closed vessel had received attention. The introduction of an apparatus combining not only this principle but also that of the reduction of pressure resulting from the condensation of steam in the same vessel, together with valves and cocks which enabled the operations to be repeated indefinitely, was embodied in a remarkable manner in a practical machine for raising water, patented and constructed in 1698 by Thomas Savery (b. 1650, d. 1715) and known as the "fire engine" (*see* No. 7). Whether Savery was indebted in any way to the labours of the Marquis of Worcester (*see* No. 5) and others, we do not know, but it may safely be said that he was the first to utilise fuel as a practical means of performing mechanical work. Already there existed a great sphere for the employment of such an engine in the drainage of mines; Savery appears to have erected several engines for this purpose, but their range was limited by the materials and methods of boiler construction then known, to a maximum lift of about 80 ft.; hence a mine of even moderate depth would require a number of engines at intervals, one delivering into the sump of another. This drawback, and the danger of explosion owing to the lack of a safety valve, greatly restricted the employment of the engine, so that it was in positions demanding only a single lift (*see* No. 8) that we find it to have been much used.

Meanwhile, after many years' work Thomas Newcomen (b. 1663, d. 1729), assisted by John Cawley (d. 1717), both of Dartmouth, who had been following in Papin's steps, had succeeded prior to 1712 in perfecting the atmospheric engine, from which the growth

of the modern steam engine can be clearly and continuously traced. However much Newcomen was indebted to the work of his predecessors, the atmospheric engine must be regarded as so much in advance of anything which had gone before as to be practically a new creation. Newcomen adopted a separate vessel in which to generate the steam ; furthermore, he hit upon the idea of injecting cold water into the cylinder in order to effect a speedy vacuum under the piston, but had, in consequence, to overcome the further difficulties caused by the condensed water and the air carried in along with the steam and water ; lastly, to enable the machine to regulate and repeat its movements automatically, Newcomen provided valve gear. The engine thus equipped was applied to work a lifting or bucket pump by means of a lever or wooden beam (*see* No. 11). This and the vertical position of the cylinder necessitated by the water packing were features that survived for many years after the conditions that rendered them necessary had ceased to exist. As Savery's patent was sufficiently general to cover Newcomen's invention, although quite different in principle, and as it had been extended for twenty-one years, *i.e.*, till 1733, they appear to have come to some understanding, for we find that the invention of the latter was exploited under the patent of the former.

It is scarcely possible to overestimate the importance of the Newcomen engine, which in practically its original condition remained for upwards of sixty years the only economical and powerful agent for draining mines. So rapid was its adoption that Smeaton found that down to 1769 nearly 100 engines had been built in the Northern coal districts and about half that number in Cornwall.

In 1763–4 James Watt (b. 1736, d. 1819), while engaged in repairing a working model of Newcomen's engine, found the consumption of steam to be much greater than he had imagined, and was thus led to make experiments and careful measurements of the temperature, pressure, and volume of steam, and also of the quantity of water required for its condensation. By these investigations he discovered that the chief waste in the engine arose from the cooling of the cylinder and piston surfaces by the water-spray used to condense the steam in the cylinder ; this led in 1765 to his brilliant invention of the separate condenser, an improvement which at once halved the fuel consumption of the engine. The use of a snifting valve being impracticable, Watt devised the air pump to clear out both air and water from the condenser. He then covered in the top of the cylinder to exclude the cooling action of the air and exposed it to steam from the boiler. He thus produced the single acting beam pumping engine, a machine which is still employed with most economical results for raising water (*see* No. 552). These improvements were secured to Watt by patent in 1769, which was extended in 1775 for a period of twenty-five years at the time when he entered into partnership for a like period with Matthew Boulton.

The next step was to employ the engine for obtaining rotatory motion, and Watt, with several others, proposed to use the oscillating

motion of the beam to drive a flywheel shaft by the intervention of a crank and connecting-rod. Watt, however, was forestalled in this application by a patent taken out in 1780, so he was obliged to resort to other means, and in a specification of 1781 described several arrangements for obtaining rotatory motion from a rocking beam, including the "sun and planet" gear, with which all his mill engines were fitted till the crank patent expired. To obtain regular reciprocation from the single-acting engines, a weight equivalent to half the load of the piston was at first fixed on the connecting-rod or at its end of the beam, but it soon became evident that by making the cylinder double-acting, not only was the power of the engine doubled, but greater regularity in its speed was obtainable. This change, however, prohibited the use of the hitherto flexible connection, by chain and arch head, between the piston-rod and its end of the engine beam, but the difficulty was completely surmounted by Watt's introduction of the parallel motion bearing his name, which he stated to have been of all his inventions the one with which he was most pleased. These improvements were patented in 1782, and the first engine embodying them was made in 1784. From this time the engine ceased to be exclusively an appliance for raising water, and entered the much wider field of industrial employment.

The reduction in steam consumption resulting from cutting off the supply early in the stroke, and allowing the completion of the stroke to be performed by the steam while expanding, was discovered by Watt in 1769, and practically carried out at Soho in 1776, but he did not patent the invention till 1782.

The great success which attended the introduction of Boulton and Watt's engines stimulated other inventors (*see* No. 67). Among these was Jonathan Hornblower, who in 1781 patented and introduced the compound single-acting engine for pumping; the high-pressure cylinder was placed between the low-pressure cylinder and the beam centre. With the low boiler pressure in use at the period it proved less economical than the simple engine, and, as it embodied the separate condenser, was an infringement of Watt's patent.

To the last Watt was satisfied with having perfected the steam engine in its original form of a vacuum apparatus. Although he had experimented with high-pressure steam as early as 1761–2, and had included its use in his patent of 1769, he consistently opposed its introduction and restricted himself to pressures of not more than 1 or 2 lbs. above the atmosphere, owing to the risk of explosion with boilers as then constructed. Immediately after 1800, the date of expiration of his patent, an advance began which is still continuing at the present day. The vacuum has become of relatively less importance, and in the case of the high-pressure engine is dispensed with altogether. One of the first to advocate and introduce the latter was Richard Trevithick (b. 1771, d. 1833), who patented in 1802 a semi-portable engine of this type (*see* No. 76); his application of it to the locomotive engine (*see* p. 54) was, however, its most important development.

About 1800 also commenced the introduction of self-contained engines of low power, which should be more compact than the established beam type (*see* No. 70); this has gradually led up to the direct acting engine, which, although adopted in 1801 by Symington in the horizontal form, was slow in attaining recognition, but has now practically superseded the indirect type.

In 1804 Arthur Woolf reintroduced the compound engine, and by expanding the steam from six to nine times was able to demonstrate its superiority in economy over the simple engine, owing to the reduction of temperature range and consequent losses in each cylinder; with increased pressures and temperatures the principle has been extended since with great advantage to engines in which the steam is used sucessively in three, four, or even five cylinders.

The demand which arose about 1880 for engines for driving dynamo-electric machinery resulted not only in the improvement of the existing type of slow-running engines (*see* No. 93) but also in the development of a new type of high speed or quick revolution engines for direct driving (*see* No. 94), necessitating attention to such problems as balancing rotating and reciprocating parts, the use of better constructional materials to keep down weight, closer governing, and forced lubrication. With this advance and with researches into the thermodynamics of the steam engine, P. W. Willans (b. 1851, d. 1892) is closely associated.

The economy resulting from the use of superheated steam by diminishing cylinder condensation losses was known early in the 19th century, but is now carried to greater temperatures than formerly, *e.g.*, Schmidt has employed 150 deg. C. of superheat. The difficulties of lubrication have been got over by the use of mineral oil and of packing by the use of soft metals for pistons and glands.

The advantages of obtaining rotatory motion from steam without the intervention of reciprocating parts are so great that ever since the time of Watt (*see* No. 96) much attention has been paid to the subject, resulting in the discovery of many new mechanisms. Within a chamber enclosing the shaft to be driven some abutment on which an unbalanced pressure can be exerted will usually be found; in many rotary engines, however, reciprocating motion will be found to exist also. The excessive weight for the power developed has confined these engines, where successful, to low powers only.

The steam turbine, which has been developed practically within the last two decades, is also a rotary engine and shares its advantages, but differs both from it and the reciprocating type in that the working fluid acts, not by pressure, but by change of momentum. The simplest form, analogous to the impulse water wheel, consisting of a jet of steam acting on the vanes of a wheel, is very old (*see* No. 3) but inefficient. With a plain orifice there is considerable loss in converting the heat energy of the steam into kinetic energy. By using a diverging nozzle, Dr. de Laval in 1889 was able practically to eliminate this loss. To obtain efficiency the vanes should travel at about half the speed of the fluid of the jet, and as this velocity

is very great (*e.g.*, a difference of pressure of 200 lbs. per square inch gives a velocity of 4,000 ft. per second, special arrangements and reduction by gearing to obtain practical shaft speeds were necessitated (*see* No. 105). To avoid exceeding these ordinary limits of speed, Parsons in 1884 arranged side by side on the shaft a number of axial or parallel flow turbines in each of which a part of the pressure energy of the steam was converted efficiently into kinetic energy, the velocity resulting at each step being within desired limits (*see* No. 104). The condensing type introduced in 1891 demonstrated that the turbine could equal in efficiency and even surpass in the higher powers the reciprocating engine. The success of the Parsons turbine has resulted in the design of other successful types in which the number of wheels has been reduced without necessitating excessive shaft speeds (*see* No. 106); most of these will be found to be of the axial flow type.

1. Drawing of apparatus described by Hero. M.2557.

Hero of Alexandria, a philosopher who flourished probably about 150 B.C., in his treatise on "Pneumatics" describes a light ball, supported by a jet of high pressure steam issuing from a pipe terminating in a cup, and supplied from a cauldron.

He also describes the *æolipile*, which consisted of a hollow ball mounted on its axis between two pivots, one of which, being hollow, served as a steam pipe from a cauldron below, supporting the whole. The ball is provided with two bent nozzles, in a plane at right angles to the line joining the pivots. The reaction or unbalanced pressure due to the escape of the jets of high pressure steam tangentially to the ball, caused it to revolve on its axis.

2. Drawing of apparatus proposed by Solomon de Caus. M.2557.

This French engineer and architect proposed and published in 1615 an application of steam as a means of elevating water.

His scheme required a spherical copper boiler with an internal pipe reaching nearly to the bottom, and with a cock for filling it. The boiler was to be placed on a fire until the steam pressure forced the boiling water through the vertical pipe, to a height proportionate to this pressure. In an alternative scheme he proposed using the heat of the sun's rays to increase the pressure of a confined volume of air, and thus force up some of the water upon which it pressed.

3. Drawing of machine designed by Giovanni Branca. M.2557.

Branca was an Italian engineer who, in 1629, published a work in which he suggested a form of steam turbine. A powerful horizontal jet of steam was to be directed against vanes on the circumference of a fan wheel with a vertical axis, thus causing the wheel to revolve. Several applications of the resulting motion were described, but that shown in the drawing consists in the use of a reducing train of spur gearing by which pestles or gravitation stamps are lifted.

The apparatus is now manufactured as a child's toy; with an important alteration in the form of the jet and in that of the vanes it would, however, have resembled the efficient steam turbine of Dr. de Laval, provided the requisite high speed could have been maintained (*see* No. 105).

4. Drawing of apparatus of Torricelli and von Guericke. M.2557.

Evangelista Torricelli, an Italian physicist and a pupil of Galileo, in 1643 confirmed his instructor's speculations that the atmosphere had weight by measuring it with his invention of what is now known as the mercurial barometer.

Otto von Guericke, burgomaster of Magdeburg, directed his attention to the means of obtaining a vacuum and adapted the syringe for this purpose; in 1654 he showed his apparatus publicly. In the treatise he published in 1672, he described a number of experiments on the subject, including the one shown in the drawing in which a cylinder is fitted with a tight piston connected by a cord and overhead pulley to a weight; when the air under the piston was exhausted by an air-pump the weight was lifted.

5. Drawing of contrivance described by the Marquis of Worcester. M.2557.

Edward Somerset, second Marquess of Worcester, in his "Century of Inventions," which was written in 1655, although not published till 1663, included descriptions of "An admirable and most forcible way to drive up water by fire" and of a "water work"; in 1663 the benefits of a "water commanding engine" were secured to the Marquis for ninety-nine years by Act of Parliament.

In 1663 and 1669 eye witnesses saw one of these engines, which had been erected by the Marquis at Vauxhall, raise water to a height of 40 ft.; this drawing is a speculative attempt to represent that engine. It shows a high pressure boiler, and two vessels into which the water to be pumped was forced by atmospheric pressure after the contained steam had condensed; this water was afterwards discharged by steam pressure on the system subsequently extensively practised by Savery.

6. Drawing of apparatus proposed by Papin. M.2557.

Denis Papin, in 1690, published a proposal for obtaining power by the action of steam. The apparatus was to consist of a thin, open-topped metal cylinder, fitted with a piston provided with a rod on which was a latch. A small quantity of water was to be placed in the cylinder, and be heated by an external fire till the steam generated forced the piston to rise to the top, where it was to be retained by the latch. The fire was then to be removed, so that the steam should condense, thus causing the piston when released to move towards the bottom of the cylinder with such force as to enable it, by the aid of a rope and overhead pulley, to lift a weight. Papin stated that a cylinder 2·5 in. diam. would, if thus worked, raise a weight of 60 lbs. once a minute through a height equal to the stroke; this is equal to obtaining an unbalanced pressure of 12 lbs. per sq. in.

In this proposal there is some suggestion of the principle of Newcomen's engine, but the unavoidable air leakage is not provided for; in 1707, moreover, Papin had abandoned it, and was working on an engine almost identical with that of Savery, the piston used being merely a loose wooden float to reduce the steam consumption arising from the direct contact of steam with the water to be lifted.

7. Drawing of Savery's pumping engine. M.2557.

In 1698 Thomas Savery patented an apparatus "for raising of water and occasioning motion to all sort of mill works, by the impellent force of fire." No drawing of the arrangement was deposited, but in the following year a model of the machine was shown to the Royal Society, and is illustrated in their Philosophical Transactions.

The apparatus in its simplest form consisted of a high pressure boiler supplying steam to a receiver, which was provided with suction and delivery pipes and the corresponding valves. By means of a regulator valve worked by hand, steam from the boiler was admitted into a receiver and allowed to blow through it till the air had been expelled; then the supply of steam was cut off and cold water from a cistern above was turned on to the receiver which, acting as a surface condenser, condensed the steam, so forming a partial vacuum into which the water rose from the suction pipe, the delivery orifice being at the same time sealed by its valve; the entering water further assisted in this condensation. Steam was then again admitted, and by its pressure forced the water in the receiver out through the delivery valve and pipe, the suction pipe in the meantime being closed by its non-return valve.

8. Engraving of Savery's single pumping engine. Presented by R. B. Prosser, Esq., 1900. M.3113.

This shows an engine of the single receiver type (*see* No. 7) erected by Savery in 1712 at Campden House, Kensington. It is stated that the suction pipe was 16 ft. long but that it could be made to draw water about 28 ft.; that the steam pipe was ·5 in. diam. and the suction pipes 3 in. diam.; that the receiver held 13 gallons of water; and that the height from engine to cistern was 42 ft. As the receiver was emptied four times per minute, the useful capacity of this engine was nearly 1 H.P.

9. Drawing of Savery's double pumping engine. M.2557.

This arrangement is shown in Savery's treatise, "The Miners Friend," published in 1702 in order to bring his engine into public notice as a means of draining mines. It shows two receivers acting alternately, but supplied from one steam boiler; there is also a smaller boiler for supplying the feed water to the main one, but there appears to have been no safety valve on either boiler. The vessels are of hammered copper, while the valve boxes and regulator are of brass and the pipes of wood. Steam was admitted alternately into the two receivers by a single regulator.

The coal consumption, as determined by Smeaton in an engine built in 1774, was 30 lbs. per H.P. hour in water pumped, the "duty" being about 7·3 millions of foot-pounds per 112 lbs. of coal burnt.

In a greatly improved form Savery's engine has been reintroduced, and with modern additions and workmanship is well known as the "pulsometer" steam pump (*see* No. 611).

10. Drawing of the "fire mill" proposed by Amontons. M.2557.

This design was submitted to the French Academy of Sciences in 1699 by Guillaume Amontons, but it suggests a hot-air engine rather than one working by steam. It shows a closed cylindrical copper drum, 31·8 ft. diam. by 12·8 ft. wide, divided into twelve compartments by radial partitions, and containing a smaller concentric wooden drum similarly divided. The partitions of the inner drum are fitted with flap valves and are partially filled with water, while a curved copper pipe leads from each of its chambers to a corresponding chamber of the outer wheel. The drum is mounted on a horizontal axle, and on one side is a furnace to heat the air in the chamber nearest to it, so that the resulting increased pressure and volume being transmitted to the lower cell of the inner or water drum will force the water through the clack into the next higher chamber, and so on, thus continually keeping the water at a higher level on one side of this virtual water wheel than it is on the other, and thereby causing the drum to revolve. After the heated air had done its work it was to be cooled by the water in which the lower part of the drum was immersed. Amontons estimated that the above apparatus was to be equivalent to no less than thirty-nine horses, but his determination of the working capability of a horse was about 14,000 foot-pounds per minute; this he considered was equal to the effort of six men.

11. Drawing of Newcomen's pumping engine. M.2557.

About the year 1712 Thomas Newcomen, of Dartmouth, assisted by John Cawley, introduced this machine, known as the "atmospheric" engine, in which were first embodied on a practical scale several of the leading features of the reciprocating steam engine. The engine was exploited under the patent granted to Savery, and, at the time, much confusion existed regarding the two inventions. Newcomen, however, by the introduction of the piston, was enabled to force water to any height, without using steam of higher than atmospheric pressure.

Newcomen's pumping engine consisted of a vertical open-topped cylinder fitted with a piston which, by chains, was connected with one end of a beam; the other end of the beam was similarly connected with the vertical rods of a pump, which might be at any requisite depth and of a size suited to the lift to be performed. The centre of the beam was fitted with trunnions, so that it could oscillate, and its ends were provided with arch-heads in order that the chains resting on them should remain vertical while the beam worked. The cylinder was placed on the top of a boiler, so that when a valve was opened, steam could enter the cylinder and allow the piston, which was being pulled up by the weight of the pump-rods at the other end of the beam, to rise. When the piston had reached the top of the cylinder the steam was shut off, and cold water from an overhead cistern was admitted in a jet at the bottom of the cylinder, thus condensing the steam and leaving a partial vacuum, so that the piston was forced downwards by the pressure of the atmosphere; when this down or working stroke was completed, the injection water was cut off. Steam was then again admitted for the

next up stroke, during which the hot water at the bottom of the cylinder was being discharged through an eduction pipe terminating in a non-return valve while air that had come in with the steam and injection water was blown out through a "snifting" valve, so called from the noise it made; both these were seated in cisterns filled with water.

The ingress of air, which would have been fatal to the action of the engine, was prevented by keeping the top of the piston flooded with water; that which leaked past the piston was delivered with the water used for condensation, during the up stroke. Soft packing was used on the piston, as cylinders could not at that time be bored; they were made of brass cast as thin as possible to reduce the heating and cooling losses.

The steam and injection valves of the engine were sometimes worked by hand; indeed, one is so worked at the present day, but it was very early in its history that these motions were given by a float in the boiler or by mechanism connected with the oscillating beam (*see* No. 12).

12. Photograph of a print of a Newcomen engine. Presented by R. L. Galloway, Esq., 1880. M.2570.

This is taken from an engraving, dated 1719, showing the steam engine erected in 1712 by Newcomen near Dudley Castle, Staffordshire. It is of great interest as fixing an early date for the automatic valve gear, and shows that the engine was then in a very complete state. Detailed references to all the parts and several particulars are given, from which it appears that the engine had a brass cylinder 21 in. diam. and 7·83 ft. high, carried on a boiler 6·08 ft. high and 5·5 ft. diam. It worked two pumps, each having a lift of 75 ft., and when making 12 double strokes per min. raised 120 gallons of water to an elevation of 150 ft., which is equivalent to 5·5 H.P. in useful work done.

The valve gear is worked by a sliding beam or plug rod attached by chains to a smaller arch-head on the beam and extended below to work a plunger pump for filling the cistern whence injection and other water supplies were drawn. This plug rod actuated the regulator or steam valve, which was simply a sector-shaped plate, at the end of each down stroke and of each up stroke. A stirrup attached to the regulator was jerked to and fro by a ⅄ or forked tumbler bob fixed to the same shaft, as were two tappets struck by pins in the plug rod. The F-shaped injection cock handle was held by a catch till tripped by a rod projecting from a buoy floating on the surface of water inside a pipe passing through the top of the boiler. A pause, whose length depended on the pressure in the boiler, would ensue with the piston at the top of the stroke. The injection cock was replaced in its catch by a pin in the plug rod. The print affords evidence that the duty of tripping the injection cock had been, at the date of the print, transferred to the "scoggen," a hinged bar struck by a pin in the plunger rod. The pause at the top of the stroke was suppressed so that a greater number of strokes were made in a given time; this would explain Reference 13, "Scoggen and his Mate, who work Double to the Boy, γ is the Axis of him."

13. Model of a Newcomen engine (working). Made in the Museum, 1891. Plate I., No. 1. M.2421.

This is a full-sized copy of a model, now in the Museum of King's College, London, and probably made by Dr. J. T. Desaguliers about

the year 1740; in a few unimportant details the original, which is now imperfect, has not been absolutely followed.

The machine consists of a boiler, 8·75 in. diam., directly above which is a vertical cylinder fitted with a piston, 2·25 in. diam. by 7·75 in. stroke. A chain from the piston is attached to one end of a beam capable of swinging on a central gudgeon. To the other end of this beam a similar chain is secured, and carries the pump rods which are connected with the buckets of two vertical pumps, 1·25 in. diam. placed below the shaft of the mine to be drained, and which divide the total lift into stages of 50 ft., as the pipes, which were hollowed taper poles, could not resist a higher pressure than that due to this height. Both the steam valve and the injection cock are actuated by pins in the plug rod.

The following table shows approximately the best results obtained at various dates as the steam engine subsequently developed, the figures giving the "duty" or foot pounds of water pumped for every 112 lbs. of coal consumed:—

1718.	Newcomen	4·3	millions
1767.	Newcomen, Beighton, and Smeaton	7·4	,,
1774.	Smeaton	12·5	,,
1774.	Watt (separate condenser)	21·0	,,
1778.	Watt (separate condenser and expansion)	31·0	,,
1800.	Watt (separate condenser and expansion)	66·0	,,
1842.	Cornish engine and boiler, with high pressure	100·0	,,
1883.	Waterworks engine (compound) ..	120·0	,,

Notwithstanding their low efficiency, Newcomen engines are still working at one or two collieries where waste coal is available, the absence of pressure enabling their steam to be generated in boilers that would otherwise be unworkable.

14. Photograph of a print of a Newcomen engine (1725). Presented by R. B. Prosser, Esq., 1906. M.3468.

This is a reproduction, reduced in size, from a copper-plate engraving dated 1725, preserved at the British Museum, which has, at the sides, the letterpress shown.

It is interesting as showing the advances made in the interval between the engine erected at Dudley Castle in 1712 (*see* No. 12) and this one. The boiler is fed partially with the hot water coming from the bottom of the cylinder, and as a result the number of strokes has increased from the 10 or 12 strokes previously known to about 16 per min. There are two gauge cocks to the boiler, which enable both high and low water to be tested; there is also a dead weight safety valve. An independent jack head pump, instead of the plug rod, supplies the injection water cistern. The valve gear has the buoy arrangement (*see* No. 12).

15. Drawing of Newcomen engine, near Bristol. (From "Engineering," October 25th, 1895). M.2570.

This engine is believed to have been built in 1750 for draining a coal-pit 750 ft. deep at Bedminster, a duty which it successfully performed

by working three or four hours a day till 1900, when it was dismantled. Steam was originally supplied by two haystack boilers, but reduced steam from a later boiler has been used since they became unserviceable.

The cylinder was 66 in. diam. by 6 ft. stroke, and weighed with its conical base about 6 tons. The piston was packed with rope weighted with pig-iron, and had three rods and chains connecting it with the arch-head at its end of the beam. The beam was of oak trussed with iron, and weighed about 5 tons; its length was 24 ft., and depth 4 ft. At the base of the cylinder were its three valves: a circular lift-valve for the steam, a slide for the injection, and a clack for the condensed water. At the pump end of the beam were three chains connected with three lift-pumps of 9·75 in. diam., one delivering into another so as to divide the lift into three stages. The jack-pump was worked by a separate chain attached to the main piston. The engine, making ten double strokes per minute, indicated 52 H.P., while the water pumped represented about 44 H.P. It is thermally rather than mechanically that such engines are inefficient.

16. Photographs of Newcomen engine in Fairbottom Valley, Lancashire. Received 1900. M.3114.

These prints show with considerable detail the pumping engine known as "Fairbottom Bobs," erected at Bardsley between Ashton-under-Lyne and Oldham, as it appeared in 1860. Little is known of the history of the engine, but it is generally reported to have been built in 1750, and to have been re-erected at Bardsley about the end of the 18th century, where it worked till 1827, pumping from the Cannel Mine at a depth of 225 ft.

The cylinder is 27·4 in. diam. by 6 ft. stroke, and is a single casting; air was prevented from leaking past the piston by a packing of peat or hemp, and the injection jet discharged directly into the cylinder. The beam is 20 ft. long, built up of two 12 in. by 14 in. oak timbers trussed with iron, and its bearings are supported by a masonry pillar 14·5 ft. by 7·25 ft. at the base. Steam was supplied by the wagon boiler, 6·25 ft. wide, 7 ft. high by 17 ft. long, shown in the photograph, but it is probable that the original boiler was of the haystack form.

17. Photographs of a Newcomen pumping engine. Presented by Messrs. James Joicey & Co., 1891. M.2375.

This atmospheric engine was built in 1754 by the Coalbrookdale Iron Co., and erected at the Tanfield Moor Colliery, Durham. It had an open topped cylinder 48 in. diam., and a stroke of 7 ft. indicating probably about 35 H.P. It lifted water from the Hutton Seam at a depth of 393 ft. into the delivery drift at 174 ft. below the surface, giving an actual lift of 219 ft. It stopped pumping in 1876, and these photographs were taken in 1891 when the engine was being dismantled. In one view the old haystack form of boiler is seen.

Since starting, the engine had been considerably modified by the removal of the original wooden beam and arch-heads, these being replaced by a cast-iron beam and Watt's parallel motion.

18. Drawing of atmospheric engine at Cronstadt. (Scale 1 : 36.) Woodcroft Bequest, 1903. M.3288.

This longitudinal section represents the Newcomen engine, designed by Smeaton in 1773, constructed at Carron Iron Works, and erected at Cronstadt in 1777 for emptying the graving docks. These docks had been commenced by Peter the Great in 1719 and completed in the next reign, but they were of little use owing to the two pumping windmills provided to discharge them proving unequal to the work. Smeaton's engine was similar to that which he and the Carron Co. had constructed in 1775 for Chasewater Mine, in Cornwall, but was rather smaller; another similar engine was at the same time erected at the Carron Works where it remained intact till 1873.

The Cronstadt engine was of about 100 H.P., having a cylinder 66 in. diam. by 8·5 ft. stroke, an effective pressure on the piston of 8·3 lbs. per sq. in., and making from 10 to 13·5 double strokes per min. It worked two pumps side by side each 26 in. diam. with the same stroke as the cylinder, and the height of lift varied from 33 to 53 ft., so that about 60 H.P. was the useful capacity of the plant. The injection pump, 11 in. diam. by 5 ft. stroke, raised water to a cistern which was at the top of the engine house 52 ft. higher. The links of the four chains were of cast iron, each 4 in. by 2·37 in. in section; the pins were of wrought iron 2 in. diam. and the load was distributed between the chains by equalising links. The beam was built up of 20 balks of fir, the four centre ones being 12 in. sq. and the outer ones 12 in. by 6 in.; these were bent to enclose the axle and held by straps, through bolts and wooden keys.

Three cast iron boilers were provided, of a type then frequently employed; they were of the haystack form and all joints were made by flanges and bolts. Each boiler was 16·3 ft. high by 10 ft. diam., had a grate area of 20·2 sq. ft., and weighed 15·5 tons.

19. Drawing of Newcomen engine at Kilmarnock. Presented by Robert Kennedy, Esq., 1898. M.3032.

The engine represented was erected in 1806 at Caprington Colliery, and was at work occasionally as late as 1901, when it was removed to the Dick Institute at Kilmarnock. The original timber beam with horsehead ends and chains was, however, replaced about 1850 by the present cast-iron beam with Watt's parallel motion.

The open-topped cylinder is 30 in. diam. by 63 in. stroke; the main pump is 9 in. diam. by 63 in. stroke, and had a lift of 170 ft. The jackhead, or boiler-feed, pump and the service pump are both 5·875 in. diam. by 31·5 in. stroke. The boiler pressure was ·5 lb. per sq. in., and during condensation the cylinder pressure fell to 8·5 lbs. below atmospheric; the mean value was 7·16 lbs. The engine made twelve working strokes per minute, and indicated 9·65 H.P., while the pump indicated 8·32 H.P. A copy of an indicator diagram taken in 1897 is attached.

20. Drawing of pumping engine proposed by Leupold. M.2557.

Jacob Leupold, in 1724–7, published a sketch and description of a proposed high pressure engine for working a force pump. There were to be two vertical single-acting steam cylinders, two pumps, and two rocking beams; but the steam and exhaust for both cylinders

were to be controlled by a single four-way cock, so that the cylinders worked alternately. The weight of each steam piston was to exceed that of the pump plunger at the other end of its beam so that the in-strokes would be done by gravity, while the exhaust steam passed into the atmosphere.

The use of a non-condensing engine and of a four-way cock which Leupold pointed out could be automatically worked, are the leading features in this proposal.

21. Original experimental model of a separate condenser, made by James Watt, 1765. Watt Collection, 1876. Plate I., No. 2. M.1823.

This, although incomplete probably shows the original apparatus by which Watt demonstrated the soundness of his first invention in connection with the steam engine, the subject of his patent of 1769.

It consists of a steam jacketed cylinder 1·4 in. diam. fitted with a hemp-packed piston. From the piston a rod passed downward through a gland and terminated in a hook from which a weight of 18 lbs. was suspended. At the side of the cylinder is a vertical pipe closed at the top, but opening into the cylinder, and secured below into a metal box. From the top of this box also passes upward a vertical tube which was the barrel of the air-pump. From the top of the closed vertical tube—which is the separate condenser—projects a small tube closed by a snifting valve, opening outward. The condenser and air-pump were enclosed in a cistern of cold water, and the air-pump was fitted with a piston. A sectional drawing of the apparatus is attached.

For some unknown reason the model is now soldered together in an unworkable manner. Possibly Watt, after his experiments and before his patent was secured, felt that the model might fall into dishonest hands, and therefore left it in this misleading shape, with the steam jacket opening into the condenser and the hole in the cylinder end, and at J soldered over. That the condenser pipe E originally joined the cylinder at the now closed hole at J is proved by the curved notch filed in the cylinder cover, which notch is now purposeless, but would be necessary with the condenser in the higher position; the short pipe from J into the cylinder also admits of no other explanation. Steam to the jacket entered at B, and there is a small hole in the lower cover of the cylinder to act as a drain. By a cock, steam was admitted into the cylinder through the now closed hole in the top cover, and filling the cylinder it blew through into the upper part of the condenser and out at the snifting valve at G. When all air had been so displaced the steam cock was shut and the piston in the air-pump H was pulled up by hand, thus leaving an exhausted and cold chamber at F into which the steam from the cylinder rushed and was immediately condensed. As the weight then lifted by the piston was 18 lbs., the condenser pressure was nearly 12 lbs. below that of the atmosphere, and corresponded to a vacuum of 24 in. of mercury.

22. Original model of a surface condenser, made by James Watt. Watt Collection, 1876. Plate I., No. 3. M.1824.

This model, which was probably made very shortly after No. 21, is complete, and shows an excellent surface condenser and air-pump,

The condenser is circular, and is traversed by 140 small tubes soldered into a metal tube plate at each end. The cooling water passes through the interior of the tubes. A vertical air-pump is attached to the side of the casing, and consists of two tubes united below. The shorter one is the barrel of the air-pump and is fitted with a solid piston. The longer one is fitted with a delivery valve at the top, and a suction valve where it is connected with the lower end of the condenser. The exhaust steam entered the upper portion of the condenser and the lower outlet opened into the column of the air-pump in such a way that the rising and falling of the water column with the motion of the air-pump piston removed all air from the condenser, and delivered it before discharging the water. In this way an excellent vacuum would be maintained, and modern engine air-pumps are only found efficient when they accord with the principles here observed by Watt.

Through the difficulty found in maintaining this form of condenser tight, Watt soon discarded it for the jet form, but now with improved methods of construction the tubular surface condenser is the form most in use, chiefly owing to the supply of pure water that it gives ready for returning into the boiler.

23. Photograph of early Watt engine. Presented by G. R. Jebb, Esq., 1898. M.3036.

This engine was constructed in 1776 by Messrs. Boulton and Watt for the pumping station of the Birmingham Canal Navigation at Rolfe Street, Smethwick. It is believed to be the first engine sold by the makers, and is the oldest in existence embodying Watt's first improvement on Newcomen's engine.

The engine was worked regularly till 1892, and occasionally afterwards till 1898, when the house was demolished, and the photograph taken, prior to the removal of the engine to its future resting place at Ocker Hill, Tipton, where it is being preserved in working condition. The cylinder is single-acting, 32 in. diam. by 8 ft. stroke; the beam is of timber with horsehead ends and iron tie rods.

24. Portions of an early pumping engine. Presented by Messrs. Branson & Gwyther, 1861. M.317.

These formed a portion of the engine "Old Bess," which was erected at Matthew Boulton's metal rolling works at Soho in 1777, and remained in use till 1848, when the business was discontinued. Upon the engine being dismantled a small furnace was discovered beneath the steam cylinder, and it was reported that it had been added by Murdock with the object of reducing the steam consumption. A full description of the engine is given in No. 25. The portions preserved comprise the steam cylinder with its piston and rod, one length of the pump barrel, the complete beam with its chains and the main bearing.

25. Model of the "Old Bess" engine (working). (Scale 1 : 12). Made in the Museum, 1894. Plate I., No. 4. M.2559.

This model, which has been constructed from the data given by the existing portions of the engine, together with those on two early drawings, shows the general arrangement of the engine erected at

Boulton's works at Soho in 1777. It embodied the first improvements made by Watt upon Newcomen's pumping engine.

James Watt's first steam engine was constructed and tried at Kinneil in Scotland in 1769, and was sent to Birmingham in 1773. At Kinneil the engine, although it had a separate condenser (*see* No. 21) and embodied other improvements, was hardly a success owing to its defective mechanical construction. When Watt joined Boulton the engine and boiler were conveyed from Scotland by water *via* Hull to Birmingham, and for two years the engine was being rebuilt and improved, until, with a new bored cast-iron cylinder, it worked fairly well. It was known as "Beelzebub," and had an 18 in. cylinder, 5 ft. stroke, and worked an 18·5 in. pump against a 24 ft. head. In 1777 it was destroyed by fire, but "Old Bess" was constructed immediately afterwards to do the same work as the destroyed engine; it was, however, of considerably more power, as the steam cylinder is 33 in. diam. with a 7 ft. stroke, and the pump has a diam. of 24 in.

Matthew Boulton, when James Watt first knew him, was an extensive manufacturer of ornamental articles, and to drive his metal rolls and coining machinery utilised the power of two water-wheels, which, in dry weather, were assisted by from six to ten horses. The pumping engine "Beelzebub," and afterwards "Old Bess," was constructed to pump water from the tail-race back into the head-race of a water-wheel of 24 ft. diam., and 6 ft. breast, at times when the river flow was insufficient. This indirect method of obtaining rotary motion by steam power had previously been employed in London and elsewhere. Long after the introduction of the rotative steam engine, however, this method of driving was still practised for textile machinery, owing to the more regular motion that it was considered was obtainable by the intervention of a water-wheel. The power lost must, however, have been considerable, for if the mechanical efficiency of the water-wheel and its gearing was 50 per cent. and that of the pumps 80 per cent., the combined efficiency could only be 40 per cent., which would be only one half of the mechanical efficiency of a directly rotative engine, so that twice the amount of coal then necessary would be consumed in doing the required work. Higher speeds, heavier fly-wheels, and improved governing, soon reduced the advantage that the water-wheel possessed, and now the governing of steam engines is far easier and more nearly perfect than is usually the case with water motors under like variations of load.

26. Model of a single-acting beam pumping engine. Watt Collection, 1876. M.1804.

This is a working model of an engine resembling the present Cornish pumping engine, and in its arrangement and details is somewhat similar to the "Old Bess" engine (*see* No. 25); but it is of later date, as both piston and pump rod ends are guided by Watt's parallel motion. The condenser, which is very small, is arranged in a tank, and by its side is the air-pump, which is driven by a prolongation of the plug rod. The valve gear is of the latch type driven by tappets from the plug rod. The parallel motion for the plug rod is derived from the parallel point by an additional pantograph. The pump is in a large wooden tank, and has its bucket weighted with lead to represent the heavy spear rods of a mining pump.

27. Drawing of Watt's single-acting pumping engine. (Scale 1 : 28.) M.2557.

This represents the arrangement supplied by Messrs. Boulton & Watt in 1788, but it only differs in detail from the standard Cornish pumping engine now so extensively used.

The engine valves are of the drop type, connected by racks and segmental arms with levers struck by tappets on the plug or air-pump rod; the top valve admits steam to the cylinder, and was known as the "expansion" valve, as it was set to cut off steam at about half-stroke, thereby allowing the remainder of the stroke to be performed by the expansion of the steam previously admitted without further demand upon the boiler. The lower or "equilibrium" valve is opened when the piston reaches the bottom of its stroke, thus allowing the steam above the piston to pass to the lower side, so that by the weight of the pump-rods the piston ascends to the upper end of the cylinder. The lowest valve controls the passage from the lower end of the cylinder to the condenser, and is open throughout the down-stroke of the piston.

The well-known high economy of these engines is largely due to their acting somewhat as if compounded, since the upper portion of the piston and cylinder are never exposed to the low temperature of steam discharging into the condenser; the cylinder also has a steam jacket. The closed top cylinder here employed was introduced by Watt in 1774. The boiler shown is of the "waggon" type (*see* No. 264), and probably worked at about 5 lbs. per sq. in. above atmospheric pressure.

28. Sectional model of twin cylinder engine, by James Watt. Watt Collection, 1876. M.1820.

This is a double cylinder engine in which both cylinders are single-acting, but have their piston rods connected by a chain so that working alternately they are equivalent to one double-acting cylinder, a fact that Watt probably soon realised, as there is no evidence that an engine resembling the model was ever constructed.

The chain passes over and is fixed to a grooved wheel carrying a crank pin at the back, which would drive a connecting or pump rod. The upper ends of the cylinders are closed but in free communication, and a non-return valve in each piston will permit steam to pass upward into this space. Below each cylinder is an air-pump and condenser, the air-pump rods being connected by a chain passing over and fixed to a smaller wheel (now missing) on the overhead shaft. At the foot of each cylinder is a steam valve and an exhaust valve, by which communication is opened alternately with the boiler and the jet condenser which is in the eduction pipe leading to the air-pump.

29. Models of an inverted cylinder pumping engine, made by James Watt. Watt Collection, 1876. M.1806 & 1806A.

This arrangement of direct acting pumping engine was proposed by Watt in 1765–6 when introducing his separate condenser, but abandoned in favour of the beam constructon adopted by Newcomen. It is now usually known as the "Bull" engine, owing to its having been introduced and constructed on a practical scale by William Bull and his son Edward, who in conjunction with Trevithick, erected several

important pumping plants in Cornwall. They were, however, infringing Watt's patents, and in 1793–5 were stopped by legal proceedings.

The cylinder is supported over the pumping shaft by beams extending across the engine house, and the piston rod passes through the bottom of the cylinder and is directly attached to the pump spears, the weight of which performed the downward stroke of the pump (*in the model it is assisted by a leaden weight*). Beneath the cylinder is a short rocking beam by which some of the weight of the spears is counterbalanced, and from which the motion for the valve gear and air pump is obtained.

From the sectional model it is seen that the exhaust pipe is provided with a jet and used as a condenser, which is cleared by a vertical ir-pump; the jet is, however, intermittent, being controlled by the valve gear so that it is only turned on during the exhaust stroke.

ROTATIVE ENGINES.

30. Model of sun and planet gearing, made by James Watt. Watt Collection, 1871. M.1811.

Watt was working on the application of the crank and connecting rod to an engine beam as a means for converting its reciprocating into circular motion when he was forestalled by the patent taken out in 1780 by James Pickard, who, it is generally thought, obtained his information through one of Watt's workmen; Watt, instead of contesting the patent, decided to adopt other mechanism. This, and the four succeeding models show some of these mechanisms which he patented in 1781; of these, however, only the sun and planet gear came into use. It consists of a spur-wheel keyed to the fly-wheel shaft, and an equal spur-wheel securely fixed to the connecting rod end. The connecting rod end is tied to the fly-wheel shaft by a link which keeps the wheels in gear, but, being free on the shaft, transmits no power. The arrangement causes the fly-wheel to revolve at twice the rate at which it would if actuated by a simple crank and connecting rod, the extra revolution obtained being due to the fact that the planet wheel, although going round in a circle, does not revolve on its own axis. In some of Watt's models the sun and planet wheels are of unequal diameter, so arranged that the speed of the fly-wheel shaft is only about 50 per cent. greater than would be obtained by a simple crank.

31. Model of a ladder connecting rod, by James Watt. Watt Collection, 1871. M.1789.

This model shows a connecting rod with a long rack, composed of rungs capable of acting on either side of a pinion fixed on the fly-wheel shaft of the engine. The connecting rod is guided by a roller at the lower end, which works in a large opening of special form in a fixed guide plate which keeps the rack in gear with the pinion on the fly-wheel shaft. The arrangement somewhat resembles the mangle wheel motion reversed.

32. Model of a ladder connecting rod, by James Watt. Watt Collection, 1871. M.1790.

This model is similar to No. 31, and shows a connecting rod with a rack at the end composed of rungs capable of acting on either side of a pinion fixed on the shaft of the engine. The rod is kept in gear during a portion of each stroke by two fixed pins or rollers outside the rack, while on turning the dead centres, projecting pins, one at each end on opposite sides of the rack, are guided by the curved edges of plates fixed to the framing.

33. Model of an internally geared connecting rod, by James Watt. Watt Collection, 1871. M.1790A.

This model shows a mode of communicating the motion of the beam of an engine to a rotating shaft, by forming a large internal spur-wheel on the connecting rod and gearing it into a spur-wheel on the shaft, the teeth being kept in gear by means of a roller at the bottom end of the connecting rod, which works in a fixed oval shaped guide below the shaft.

34. Model of a crown cam motion adapted to a winding gear. Watt Collection, 1876. M.1821.

In this model the reciprocating motion of the engine beam is caused to oscillate a lever, having a conical roller mounted on it at each end, the centre on which the lever moves being close to the vertical shaft, on which is mounted a crown cam of considerable throw and also a heavy fly-wheel. By the reciprocation of the beam of the engine the conical rollers are caused alternately to press upward against the edge of the crown cam, and through the inclined action, thus to force it round. The fly-wheel carries the cam over its dead centres. A spur-pinion on the fly-wheel shaft gears into a large spur-wheel formed on the winding drum.

35. Model of a beam engine with sun and planet motion. Received 1869. M.1175.

This is a model of an early double-acting rotative beam engine. It has a wooden framing, beam and connecting rod, Watt's sun and planet motion, and a tappet motion driving a toothed segment and pinion for actuating a four-way cock for steam admission and exhaust. A small circular saw is fixed in position and is driven by the engine.

36. Boulton and Watt's rotative engine. Presented by Matthew Piers Watt Boulton, Esq., 1861. Plate I., No. 5. M.318.

This engine was erected at Soho, near Birmingham, in 1788, where it was known as the " Lap " engine, from its driving the machinery for lapping or polishing steel ornaments. It is an early example of Watt's double-acting rotative beam engine, with separate condenser and air-pump. It was nominally a 10 H.P. engine, but indicated 13·75 H.P.

It continued to work till 1858, and three years later it was removed to South Kensington.

The cylinder is 17 in. diam. and 4 ft. stroke; the fly-wheel, 16 ft. diam., has a mortised toothed rim and drove two pinions 3 ft. diam. from the shafts of which motion was communicated by belts or gearing to 43 metal working machines. It has a sun and planet motion (*see* No. 30) for driving the shaft and tappet gear to the valves, worked by the plug frame or air-pump rod, the tappets on the rod striking the levers connected with the valves in such a manner that when one valve was closed by the tappet another valve was opened by being freed from a catch or hook that had before held it closed. The connecting rod acts in a direct line to the planet wheel, and is slightly bent in an S curve to clear the sun and planet wheels. There is a slow speed centrifugal governor, driven by a chain and pulleys; it acts upon a throttle valve of the disc type. The framing is entirely of wood bound together in a rather primitive manner by straps and bolts. The beam is of wood also, the main gudgeon being placed beneath the beam and not through it.

37. Sun and planet engine. Presented by G. Atkinson, Esq., 1885. M.1620A.

This engine was constructed by Messrs. Boulton and Watt, and erected in 1797, for John Maud, chemist and druggist, at 66, Aldersgate Street, E.C., subsequently Atkinson's Chemical Works, where it continued working until 1885, when it was taken down and presented to the Museum. The engine was of 8 nominal H.P., and had a cylinder 16 in. diam. and 4 ft. stroke, but in 1806 it was altered by the makers to a 12 H.P. engine, the diameter of the cylinder being increased to 19·25 in.

It is a low-pressure condensing engine, with sun and planet gear, similar in general construction to No.36, but the valves are driven by a crank motion instead of by tappets, and there is a separate cut-off valve moved by a cam motion to give expansive working. The crank and cam are both on a counter-shaft driven by spur gearing, at one half the speed of the fly-wheel shaft, which, on account of the sun and planet gear, makes two revolutions for each double stroke of the engine. The connecting rod from the valve crank-pin is made with a gab end, so that it can be disengaged, and the valves be worked by hand levers when required in starting the engine. The engine was probably made with a tappet motion in the first case, and the motion above described added at the later date.

38. Drawing of mill engine with sun and planet gearing. (Scale 1 : 16.) M.2557.

This shows the standard type of factory engine constructed by Messrs. Boulton and Watt from 1787 till 1800. It represents a 10 H.P. engine built in 1795 for a starch works in Lambeth; it made 50 strokes per minute, and owing to the sun and planet gearing the fly-wheel made 50 revs. per min. These engines were made in various sizes up to 50 H.P., and two examples of the smaller sizes will be found in the Museum. (*See* Nos. 36 and 37.)

39. Drawing of Symington's steam engine. Woodcroft Bequest, 1903. M.1659.

This is a copy of the drawing enrolled with William Symington's Patent Specification of 1787, which shows an atmospheric engine in which heat losses are diminished by confining condensation to the lower and enlarged part of the cylinder by means of a free piston or air-pump bucket resting, close to the surface of the cold water there, on two rods supported by a lever worked by tappets in the plug frame. A valve in this bucket is similarly worked so that when the cylinder has filled with steam and the piston has gone outdoors, this valve is opened, admitting the steam to the underside of the bucket, which at the same time is raised by its lever. The injection water is also delivered into this space. When steam is again admitted it closes the valve in the bucket, forces the latter down and displaces air and condensed water. A few of these engines were built, as the arrangement was not considered to be an infringement of Watt's patent for the separate condenser.

The cylinder is jacketed by the hot gases passing through a helical flue on their way from the boiler to the chimney.

A method of transforming reciprocating into continuous rotative motion by means of two ratchets and of two racks suspended from the engine beam is shown. This mechanism and the engine are interesting, as they were used by Symington in very early experiments on steam navigation (*see* Marine Engineering Collection).

40. Motion diagram of a beam engine. Watt Collection, 1876. M.1807.

This shows the mechanism of a rotative beam engine, similar to that represented by the models Nos. 41 and 42, in which the steam is distributed by a long D slide valve actuated by an eccentric. It was probably made when the introduction of this improved arrangement of valve gear was under consideration, for it is recorded that Watt preferred the four drop valves employed in his earlier engines and that he somewhat reluctantly consented to the adoption of the simpler slide valve of Murdock.

41. Model of a double-acting beam engine (working). Watt Collection, 1876. M.1805.

This model was probably made about the year 1800, as the valve gear and general arrangements are improvements upon those in the actual engine No. 37 erected in 1797. The framing is of timber, supported under the beam gudgeon by a metal column carried on a masonry pedestal. The beam is a casting, and has its terminal pins carried in trunnion hoops which adjust themselves to any inaccuracy in the erection. The valves are of the drop type, two for each end of the cylinder; the spindle of the lower valve in each case passes up through the tubular spindle of the upper one. The valves are driven by a quiet tappet gear from a horizontal shaft rocked by an eccentric on the crank shaft, but the valve gear does not permit of expansive working.

The beam is fitted with Watt's parallel motion, and by the looping of the lower tie rod the air-pump rod is directly connected with the

parallel point, in the way that has since been generally followed. The condenser is cylindrical and is enclosed in a water tank. To the top of the condenser is secured the air-pump, the discharge of which is led off by a shoot. The injection water is conveyed to the condenser by a horizontal pipe from outside the tank. The top cover of the air-pump is guided by three studs which permit it to lift vertically, so that it acts as a delivery valve. The steam cylinder is 1·625 in. diam. by 4·5 in. stroke.

42. Model of a beam engine (working). (Scale 1 : 8.) Contributed by C. W. Osman, Esq., 1859. M.319.

This model was made by William Tongue, while an apprentice with Messrs. Boulton & Watt at Birmingham, 1797–1804. The condenser is contained in a large rectangular tank, situated under the cylinder. This tank also contains the air-pump, which is provided with a cover carrying a stuffing box through which the pump rod passes. The cover is permitted to rise about ·12 in. by the three holding-down dogs, which, while keeping it central, permit this amount of lift. The upward motion of the air-pump rod lifts the cover as far as the clips permit, by the friction of the packing, and it is similarly lowered on the down stroke—an arrangement equivalent to a mechanically moved delivery valve.

The parallel motion here shown has an extra linked parallelogram to carry the parallel point for the attachment of the air-pump rod clear of the rods of the main parallelogram, an arrangement, however, that is not such a simple solution of the difficulty as that shown in the other beam engines.

43. Model of a single-acting rotative engine. (Scale 1 : 8.) Lent by W. W. S. Westwood, Esq., 1894. Plate I., No. 6. M.2657.

The history of this model is uncertain, but the engine shows a method of obtaining rotary motion with an open topped cylinder, and so connects the early pumping engine with Watt's double-acting rotative engine. It is said that the model was sent by Watt to Corbyn's Hall Ironworks to show how his improved engine could be applied to colliery winding.

The engine is of the beam type, has an open topped cylinder, and drives a crank-shaft by the usual connecting rod, but to equalise the motion the connecting rod is provided with a heavy weight, which absorbs one half of the work of the downward stroke of the piston, and restores it during the upward or idle stroke. Watt's separate condenser and air-pump are employed, and also his parallel motion, and the cylinder valves are driven from the crank-shaft by an eccentric and strap. The engine has a cylinder 2·625 in. diam. by 3·25 in. stroke, and was used to drive a small lathe.

Watt's patent of 1781, which describes the sun and planet gear, claims the method of obtaining rotary motion from a Newcomen engine by the use of a counterbalance weight on the connecting rod or on the rotating shaft, and the parallel motion was described in his patent of 1784; an eccentric and strap for moving the valves appear to have been introduced about the year 1800 and to have been known as Murdock's "circular" gear.

44. Cabinet steam engine, by James Watt (working). Contributed by A. Greg, Esq., 1858. M.2.

This engine was the property of James Watt, who bequeathed it to Mr. John Kennedy, of Manchester; it may be said to represent the steam engine as left by Watt. It is a small double-acting beam engine with a separate jet condenser and air-pump. The slide valve is of the long D form; the cylinder is steam-jacketed. Watt's parallel motion is employed to guide the top of the piston rod and the air-pump rod, and the simple crank and connecting rod is used to secure rotative motion. The slide valve is worked by a single eccentric, and the speed of the engine is controlled by Watt's conical pendulum governor, which acts on a throttle valve in the steam passage. The cast iron tank, standards, and beam, together with the general arrangement of the engine, hardly differ from those of similar engines of the present day.

45. Sectional wooden model of beam engine (working). Made in the Museum, 1866. M.1002.

This model is a copy of the preceding engine (No. 44) sectioned to show the internal construction; it also illustrates the general construction of the cylinder and valves of the smaller and much later beam engine No. 72.

The arrangement of the condenser and air-pump can here be clearly seen, as also the slide valve and ports, and the cylinder jacket through which the steam passes on its way to the valve chest.

The form of valve employed is known as the long D slide and is believed to have been the invention of William Murdock, whose model locomotive, made in 1781, is similarly arranged (*see* No. 108). In this valve the live steam is round the waist of the valve, and the exhaust from the upper end of the cylinder passes to the condenser through the tubular centre, the exhaust from the lower end passing directly to the condenser; the motion is accordingly exactly the reverse of the now more generally adopted short D valve. It is stated that Watt always preferred the drop form of valve, but sometimes adopted the slide on account of its simplicity.

46. Model of oscillating engine (working). Lent by W. Murdock, Esq., 1894. Plate I., No. 7. M.2554.

This is the original model constructed in 1785 by William Murdock at the Soho works. The cylinder is 1·5 in. diam., 4 in. stroke and double-acting. It is made of wood, and so was probably only tried with compressed air—a method of driving that was afterwards practically adopted by Murdock for power transmission. The framing consists of two "A" frames well braced together and supporting the shaft, which is furnished at one end with an overhanging crank and at the other with a large fly-wheel. The crank pin is directly attached to the piston rod—the cylinder oscillating on central trunnions. The outside trunnion is that through which the working fluid is introduced, while the other is merely a mechanical support. From the inlet passage the driving fluid passes by a channel to a valve chest on the side of the cylinder. The valve is a long piston of square section greatly reduced in the centre, which is the steam space. The exhaust escapes by the open ends beyond the valve. The valve spindle is continued upward

and by a V-shaped link is attached to a stationary point on the same level as the trunnions. The oscillation of the cylinder causes a longitudinal motion to the valve which gives a simple distribution of steam, but one which is not quite equal in both strokes. An eccentric in the middle of the crank shaft drives a small pump through the intervention of a lever which is so arranged as to double the stroke.

Although the model worked satisfactorily, it was forty years later before the merits of this type of engine were fully realised as the most compact arrangement for driving paddle-wheels and for many other purposes. At the time the model was made, Watt was employing the sun and planet gear to avoid using a crank.

47. Drawing of Watt's semi-rotary engine. (Scale 1 : 16.) M.2557.

This is copied from Watt's patent specification of 1782; in the Watt room at Heathfield Hall, however, there is an unfinished model of this engine, believed to have been commenced in 1766.

The engine has a short horizontal cylinder with a radial piston which can swing through an arc of 240 deg. The lower sector of the cylinder is fitted with a stationary abutment block through which steam is admitted to either side of the piston, alternately. Below the cylinders are valve boxes for the distribution of the steam, while beneath these is a jet condenser, and two air-pumps which are driven by racks from a pinion on the vibrating shaft. A large spur wheel on this shaft has two racks gearing with it, and these move the rods of the two pit pumps that the engine was designed to work; by this latter arrangement the pump-rods mutually counterbalance.

48. Drawing of bell-crank engine. (Scale 1 : 8.) M.2557.

This arrangement of engine was introduced by Messrs. Boulton, Watt and Co. in 1800 to 1806; it was designed by W. Murdock and J. Southern with the object of obtaining an engine that was self-contained, and more compact than the established beam engine.

The cylinder is vertical and double-acting, and by two vertical return connecting rods oscillates the horizontal arm of a bell-crank. From the vertical arm of the bell-crank a horizontal connecting rod proceeds to a crank on the fly-wheel shaft. A vertical air-pump is provided and is driven from the bell-crank. The engine foundation and the condenser tank are formed by one casting which carries the crank-shaft bearing. The steam is distributed by a long D-slide valve worked by an elliptical cam bolted to the fly-wheel arms.

These engines were made of from 4 to 8 H.P.; one was supplied in 1805 for Fulton's paddle steamer "Clermont"; another was in use at the Soho works till 1896.

49. Diagram model of a bell-crank engine. Watt Collection, 1876. M.1808.

This is a similar engine to that represented in the drawing, No. 48, and was probably prepared to test the general convenience of the arrangement.

The valve shown is of the long D type, but is, by an intermediate lever, driven from an eccentric on the fly-wheel shaft ; the eccentric is slotted so that its position can be adjusted.

Those portions of the model made in polished brass have been constructed in the Museum to replace pieces not preserved.

Nos. 50 to 66. These models are here inserted as forming part of the Watt Collection, but in some cases they are not directly related to the invention of the steam engine. They were presented in 1876 by Gilbert Hamilton, Esq., in the name of Messrs. James Watt & Co.

50. Model of beam and connecting rods. Watt Collection, 1876. M.1803.

In this model the horizontal lever, which probably represents an engine beam, is, by two connecting rods, coupled to two beams working in a vertical plane, at right angles to the main beam ; universal joints at each end of the connecting rods give the requisite freedom.

51. Model of flour mill driven by sun and planet gear. Watt Collection, 1876. M.1791.

One of the earliest of Watt's double-acting rotative steam engines was set to work in 1786 at the Albion Flour Mills, in Southwark, and possibly this and the succeeding model were made when that enterprise was under consideration. The mill was a success and did much to popularise the steam engine, but was destroyed by incendiarism in 1791.

In the model the engine beam transmits its motion by a connecting rod to two sun and planet motions, the driven shafts being in one line and each having a fly-wheel. Each shaft drives a set of three pairs of stones by a bevel wheel on the fly-wheel shaft gearing with a bevel wheel on the vertical shaft, which also carried a spur wheel gearing with three pinions, one on each of the mill spindles. The backlash of the sun and planet gearing is greatly reduced by using double wheels forming step gearing, also the planet wheels are only half the diameter of the sun wheels.

52. Model of a flour mill driven by a crank and connecting rod. Watt Collection, 1876. M.1792.

In this model an engine beam transmits its power by a connecting rod which works on a crank pin placed between and carried by two fly-wheels on shafts which are in the same straight line. The shaft on one side transmits its motion through bevel wheels to a vertical shaft carrying a spur wheel gearing with the pinions on the shafts of the three mills arranged above it. The three pairs of stones of the opposite side are driven in the same way through the other fly-wheel shaft.

53. Model of rolling and slitting mill. Watt Collection, 1876. M.1793.

The plate rolls are driven through two fly-wheels by two connecting rods from the beam of an engine fitted with sun and planet motion,

having stepped spur wheels. The main bearings of the beam have top caps, thus indicating that the cylinder used would be double-acting. The slitting rolls are driven by fly-wheels gearing with those on the plate rolls.

54. Model of a rolling mill. Watt Collection, 1876. M.1794.

This mill is driven by the connecting rod from the beam of a double-acting engine, fitted with a sun and planet motion, having stepped spur-wheels.

As Boulton's works were largely engaged in manufacturing sheet metal, this and the preceding model were probably made before undertaking improvements in the plant by the substitution of steam for water power, and were prepared by Watt while testing the practical applicability of the sun and planet motion to this description of work.

55. Model of spur gearing. Watt Collection, 1876. M.1802.

This is a wooden model of a complicated train of gearing, the purpose of which is unknown, although it probably relates to some machinery for metal rolling. It was to be driven by a beam engine, the cylinder, main gudgeon, fly-wheel, and crank-shaft of which are represented. A two-speed gear is introduced, so that the effort of the engine may be further increased when on heavy work.

56. Disconnecting cranks. Watt Collection, 1876. M.1818.

The arrangement consists of two discs facing one another, one of which carries the crank pin and the other is secured to the shafting. Connection between the discs is made by three hinged tongues attached to the crank plate, and capable of being dropped into three notches in the driving disc, springs retaining these tongues in the closed or open position. An unfinished specimen of this gear is also shown.

57. Experimental beams. Watt Collection, 1876. M.1798.

These models were probably made by Watt when designing beams for his steam engines, as there is evidence that at first the engine beams gave trouble through their insufficient strength and rigidity.

The smaller beams have parallel top and bottom booms, with diagonal timber struts inclined at 60 deg.; in one case the tie bolts are inclined, and run axially through the timber struts, while in the other vertical iron tie bolts are used. In the latter case the model has been loaded to destruction.

The two larger beams consist each of a lower timber beam with a built-up truss above, the chief difference between them being that in one all the members are in duplicate. They have gudgeons and hooks or staples attached by which their strengths could be experimentally determined. From the trussing it is evident that these beams were designed for single-acting engines.

58. Model of a beam engine frame. Watt Collection, 1876. M.1799.

This model shows a complete timber framing for a beam engine. It consists of two rectangular frames, slightly inclined together at the top, and with the upper horizontal members supported under the bearings of the engine beam by two inclined struts. The main bearing for the crank-shaft is carried by an independent trestle similarly supported, and connected with the main framing.

59. Model of a marine engine frame. Watt Collection, 1876. M.1800.

This is a model in wood and metal of a massive iron framing for an oscillating cylinder engine. It is probably of more recent construction than the other Watt models.

60. Model of a forge hammer and a tilt hammer. Watt Collection, 1876. M.1795.

These are both driven by one heavy cam on an engine shaft, the forge hammer being lifted by the belly and the tilt hammer by the tail; there is provision for a spring beam over the forge hammer, to cause it to deliver a greater blow than it would by gravity alone. This model has no top cap to the main gudgeon of the beam, and the cylinder end of the beam terminates in a curved segment, or "horse head," for the reception of a chain from the piston rod, thus indicating that the engine was only single acting.

61. Model of a pair of tilt hammers. Watt Collection, 1876. M.1809.

In this model two engine beams, by connecting rods, drive cranks placed nearly at right angles on a horizontal shaft that carries two six-pointed cams. Each cam trips the end of a tilt hammer shaft, arranged on a fulcrum placed between the hammer head and the cam, the fall of the hammer being, by the arrangement, doubled.

The cranks are on discs which appear to have been intended for use as spur fly-wheels to drive other machinery, and one of the discs is provided with a heavy counterbalance.

62. Model of a grinding machine. Watt Collection, 1876. M.1796.

This appears to be a model of a machine intended for grinding or polishing metal articles. It has a horizontal shaft, carrying a lead covered lap of mushroom shape. A wooden driving pulley is attached to the shaft, for receiving the requisite power from a gut band, and sliding bearings are provided, possibly for tightening this band.

63. Wooden shaft. Watt Collection, 1876. M.1819.

This is a vertical shaft with a horizontal cross arm on which is fixed a leaden weight and two similar masses in wood. It is said to have been used in some experiments on centrifugal governors.

64. **Valve and spindle. Watt Collection, 1876. M.1822.**

An ordinary mitre seated valve is shown, guided by its spindle. The free end of the spindle is provided with a universal joint connecting it with an iron rod.

65. Model of a pump valve. Watt Collection, 1876. M.1817.

This valve was probably intended for a mine pump, but the construction is not fully shown. The staple at the top is to enable the valve to be withdrawn from above by a simple hook.

66. Model of a horse gear and crushing roll. Watt Collection, 1876. M.1801.

This horse gear is in the form of a horizontal lever turning on a vertical axis. A projecting stud on the upper side of the lever forms a crank-pin from which a connecting rod is carried to a swinging lever. From this lever two links proceed to the axle of a vertical edge runner, which can be rolled in the fixed trough. The trough has a grid bottom through which the crushed material escapes when sufficiently reduced.

67. Heslop's beam engine. Presented by the Earl of Lonsdale, 1878. Plate II., No. 1. M.1464.

This winding and pumping engine was erected about 1795 by Adam Heslop at Kell's Pit, Whitehaven, where it worked for many years; it was subsequently used at other pits in the locality till its removal to South Kensington in 1878. Particulars of fourteen other engines of this type, erected in the district, are in existence, and it is known that many more were built at Coalbrookdale (*see* Civil Engineering Collection and drawings in adjacent frames), where it is believed that the construction was first tried.

The arrangement, which is in reality a combination of a single-acting high pressure cylinder with a Newcomen engine, was patented in 1790 by Adam Heslop, although it appears to have been an infringement of Watt's patent for the separate condenser which remained in force till 1800.

There are two open-topped single acting cylinders, one known as the "hot" cylinder, 34 in. diam. by 34 in. stroke, being near the connecting-rod end of the beam, while the other, or "cold" cylinder, 25·5 in. diam. by 39 in. stroke, is at the other extremity, although in some cases both cylinders were at the same end. There is also an air pump, 12·5 in. diam. by 17 in. stroke, but this was a later addition. The steam, which was supplied by a haystack boiler, on being admitted into the hot cylinder, raised the piston by its pressure; the return stroke was made by the momentum of the fly-wheel, assisted by the weight of the connecting rod and the action of the cold cylinder. The exhaust steam from the hot cylinder passed to the cold one by an eduction pipe, which, being immersed in cold water, acted as a condenser to the extent of "killing" or reducing the steam to atmospheric pressure before it entered the cold or Newcomen cylinder; here it was condensed by an internal jet, so that the atmosphere caused a down or working stroke of this piston. All of the valves were actuated by tappets on a plug rod, and any air was expelled from the cold

cylinder by a snifting valve, which permitted a blow-through during the up stroke; this has, however, been displaced by the air pump. Pumping was done by a cast iron beam 4 or 5 ft. above the main beam, and connected with it by links, as shown in an adjacent photograph.

68. Drawing of Cartwright's engine. (Scale 1 : 8.) M.2557.

This arrangement, patented in 1797 by the Rev. Edmund Cartwright, D.D., was followed in the construction of several engines of the time. Although intended for steam, Cartwright pointed out that the engine might be worked by the vapour of "ardent spirit or ether."

A single-acting vertical steam cylinder is employed, having its piston rod carried down to the bucket of the air-pump, which is placed below in an immersed condenser of the surface type formed by enclosing a cylindrical shell within another of larger diameter. The piston is forced downward by steam pressure until it nearly reaches the bottom of its stroke, when a spring on the crosshead closes the steam valve; the spindle of an exhaust valve in the piston afterwards strikes the cylinder bottom, and so permits the steam to escape into the condenser, thus allowing the piston to pass again to the top of the cylinder under the action of the fly-wheel.

The packing of the piston and its rod are stated to have been entirely of metal, and were probably the first examples of metallic packing.

69. Model of Cartwright's engine (working). (Scale 1 : 10.) Made in the Museum, 1902. M.3253.

This model shows Cartwright's mechanism for converting the reciprocating motion of a piston into rotary motion. The engine itself presented several exceptional features (*see* No. 68), but the only other one of these followed in this model is that the valve motion is directly derived from that of the piston by a tappet action.

The arrangement for guiding the end of the piston-rod, in place of the then general parallel motion, comprised a long crosshead secured to the piston-rod and provided with two connecting-rods coupled to two cranks geared together and revolving in opposite directions. In this way the oblique thrusts of the two connecting-rods were caused to neutralise each other, and the piston-rod had only to resist the direct piston effort, which it was able to do without the assistance of a parallel motion or other form of guide.

This arrangement of mechanism was abandoned for many years, but it is now successfully employed for driving the two revolving prisms in the rotary form of air-pump known as a "pressure blower"; in such cases, however, the engine crosshead is also provided with slide guides, as shown in an attached illustration.

70. Drawing of Fenton and Murray's engine. (Scale 1 : 8.) M.2557.

This shows the self-contained or "portable" engine patented in 1802 by Matthew Murray for producing "circular power." Several engines of this type were constructed by Messrs. Fenton, Murray & Wood, of Leeds; the one represented was of 4 H.P., and was erected in 1802 for grinding bark at a Bermondsey tannery. The arrangement

is exceptionally compact, owing to the shortness of the virtual connecting-rod employed, its length being equal to one-half of the stroke only (*see* No. 71).

The engine has a vertical double-acting cylinder, with an air-pump and jet condenser in a tank below. The valves are of the drop type, and are driven by tappets on a revolving shaft connected with the crank shaft by bevel wheels.

71. Model of Murray's engine (working). (Scale 1 : 10.) Made in the Museum, 1902. M.3254.

This shows the mechanism adopted in the self-contained engine, patented in 1802 by Matthew Murray (*see* No. 70) for converting reciprocating motion of the piston into rotary motion of the shaft. It is an application of the fact, originally published in 1666 by De la Hire, that when a circle rolls within another of double its diameter, any point in the circumference of the rolling circle describes a straight line. Murray appears to have been the first to construct practically a machine embodying this method of obtaining a straight line, or "parallel" motion; he, moreover, fully describes a means of taking up the wear on the centre of the rolling wheel, by the use of adjustable double cones.

On the fly-wheel shaft is a crank-pin having loose on it a spur wheel of equal radius to the crank path, while on the rim of the spur wheel is secured a crank pin to which the piston-rod is directly attached; the spur wheel engages with an internally geared rim of double its diameter rigidly secured to the engine framing. By these arrangements a guided straight line motion is obtained without the use of links or guides, while, owing to there being no extension of the piston-rod or anything beyond it, the engine is remarkably compact. Murray's mechanism possesses the further advantages of giving a true harmonic motion, and having all its parts revolving so that they can be directly balanced, while there is a total absence of oblique thrust. For these reasons it is, although now no longer used in steam engines, still extensively adopted for giving the reciprocating motion to the tables of flat-bed printing machines as shown by a model in an adjacent room.

72. Model of a beam engine (working). (Scale about 1 : 6.) Contributed by D. Graham, Esq., 1864. M.962.

This is a model of a modern rotative beam engine made by Messrs. Miller & Ravenhill, but only in its proportions will any substantial difference be found between it and Watt's engine No. 44. The beam gudgeons are supported by two cast iron "A" frames, and there is a complete cast iron bed plate containing the condenser and air pump. A long D slide valve worked by an eccentric distributes the steam, and a large pendulum governor is provided to regulate the speed. The cylinder has a jacket which is supplied by the steam passing through it on its way to the valve chest, and not (as is more usual) directly from the boiler.

73. Model of grasshopper or half-beam engine (working). (Scale about 1 : 12.) Received 1869. M.1174.

This engine marks an intermediate type between the usual beam engine and the later form of direct-acting engine. In the grasshopper

engine the beam is only one-half the ordinary length, and the effort of the piston-rod is transmitted directly to the crank without being felt on the beam gudgeons, so that both space required and frictional loss are reduced.

In this example there is a vertical cylinder, the piston-rod of which is connected with a crosshead, from which two connecting rods pass down to a double-throw crank shaft below. The crosshead is guided by being connected at its centre with one end of the grasshopper beam, the other end being pivoted upon two rocking links, with two bridles, thus producing a straight line motion which is only a modified form of Watt's. The air pump rod obtains its movement from a straight line motion derived from the centre of the beam.

74. Models of table engines. (Scales 1 : 4 and 1 : 16.) Maudslay Collection, 1900. Plate II., No. 2. M.3121.

The original form of this engine, as patented by Henry Maudslay in 1807, is represented by an adjacent drawing, from which these models differ only in detail. Many engines of this kind were made, and some are still in existence, while, till the Lambeth Works were closed in 1900, two of them were regularly engaged there in driving some of the machinery.

The cylinder is carried vertically on a cast iron table, beneath which are the crank-shaft bearings and the condensing arrangements. The piston-rod passes through the top cover and terminates in a balancing or articulated crosshead carrying a pair of wheels which roll between guides formed in an independent framing secured to the table and the cylinder. From the crosshead there are two connecting-rods, which proceed to two independent cranks in the crank-shaft below. The steam is distributed by a plug valve rocked by a rod connected with a triangular cam on the crank-shaft. The air, cold water, and feed pumps are worked by an inverted T-bob driven by a roller on the intermediate portion of the crank-shaft.

75. Model of table engine (working). (Scale 1 : 8.) Received 1892. M.2448.

This represents a self-contained and compact form of vertical engine in which, moreover, a long connecting-rod is used; the arrangement is, however, expensive to make and unsuited for high speeds, so that the inverted cylinder type of engine has practically supplanted it.

The cylinder is mounted on a cast iron table, which is supported by four columns upon a base plate carrying the crank-shaft bearings. The piston-rod passes through the top cover of the cylinder and its crosshead slides in two pairs of guides cast with the cover. The connecting-rod is in the form of a loop, or "kite," embracing the cylinder, but clearing it sufficiently in every position, and requires only a single crank in the shaft. The slide valve is worked by a similar "kite" rod from an eccentric which also drives the horizontal force pump for feeding the steam boiler. The speed is regulated by a simple centrifugal governor which controls a disc throttle valve in the steam pipe.

76. Trevithick's high-pressure steam engine. Received 1879. Plate II., No. 3. M.1470.

This early high-pressure engine and boiler were made by Richard Trevithick in 1811 at Hayle Foundry, Cornwall, for Sir Christopher Hawkins, Bart., of Trewithen, and were in constant use for thrashing, chaff-cutting, and similar work, until removed to South Kensington in 1879. It is stated that this was the first steam engine that drove a thrashing machine.

The boiler is of the Cornish type, 7 ft. long by 4·5 ft. diam., with a single internal flue 27 in. diam.; beyond the fire bridge the circular shape is departed from, one side of the flue being flattened so that the section is 28 in. by 21 in. The products of combustion from the furnace flue were led by a "wheel draught" through external masonry flues to the chimney, the total heating surface so obtained being probably about 50 sq. ft. The shell of the boiler is shaped at the back to receive the steam cylinder, which is open-topped and placed in the boiler so as to be steam-jacketed. The safety-valve is weighted for a maximum pressure of 40 lbs. above atmospheric.

The cylinder is 9·5 in. diam. by 13 in. stroke, and the long connecting-rod, which is attached directly to the piston, passes up to a crank on a fly-wheel shaft above. The fly-wheel is 7 ft. diam., with a grooved rim for a driving rope, and has cast on it a balance weight that assists the return stroke of the piston. Steam is distributed by a three-way cock which is rocked by a cam on the crank shaft. The feed pump is worked by a lever from the piston.

77. Diagonal oscillating engine (working). Maudslay Collection, 1900. M.3125.

The double-cylinder diagonal engine with a single crank was designed and patented in 1822 by Sir M. I. Brunel, chiefly for use as a marine engine. The model shows the design as modified by the use of oscillating cylinders, and is believed to represent an engine built by Messrs. Maudslay, Sons and Field for working the drainage pumps used during the construction of the Thames Tunnel (1825–42).

The cylinders are each ·77 in. diam. by 1·43 in. stroke, and incline upward, at 45 deg., to the single crank-shaft. Each cylinder is double-acting, and the steam distribution is performed through ports in one of the trunnions, which, by its oscillation, acts as a slide-valve. As Joseph Maudslay had in 1827 introduced a much more efficient valve gear for this class of engine (*see* Marine Engineering Collection), the motor represented was probably made during the early stage of the tunnel works.

78. Diagram model of compound engine. (Scale 1 : 4.) Contributed by J. Warriner, Esq., 1857. M.128.

This design for a two-stage expansion engine was patented by Mr. J. Milner in 1853. The cylinders are side by side, with the valve chests between them, and the cranks at right angles. Reversal is affected by loose eccentrics, and a piston valve which interchanges the exhaust and steam passages.

The steam is first admitted into the smaller cylinder and is cut off at half stroke; it is then led to the larger cylinder whose piston is at the

commencement of its stroke. When the piston is at the end of its stroke, this steam will have been doing work while expanding to a volume equal to that of the low pressure cylinder and half the high pressure. This method of working causes, however, an exceptional temperature range in the high pressure cylinder.

79. Sectional model of three-cylinder engine. Presented by G. L. Fuller, Esq., 1893. M.2527.

This three-cylinder engine was patented by Mr. Fuller in 1853. It would now be described as a two-stage expansion engine with one high pressure and two low pressure cylinders. The cranks are equally spaced at 120 deg., this arrangement being adopted with the intention of obtaining uniform turning moment.

In the model the central cylinder is the high pressure one; by using two low pressure cylinders a single cylinder of inconveniently large dimensions is avoided. Into the ports are fitted cylindrical plug-valves, by rotating which the distribution of the steam to the cylinders can be varied. To assist in following the action, the high pressure steam ports and spaces are coloured red and the low pressure black.

80. Models of Perkins engine and boiler. (Scale 1 : 16.) Lent by J. Roebuck, Esq., 1903. M.3265.

The use of steam at such exceptionally high pressures as 300 to 500 lbs. per sq. in. was introduced by Mr. Loftus Perkins in several land and marine engines constructed between 1859 and 1883. His chief object was to increase the thermal efficiency of the steam engine by employing high grades of expansion carried out successively in several cylinders. As the modern marine engine works under conditions which are continually approaching those adopted by Mr. Perkins, his system no longer appears so remarkable as it did when he commenced his work. Although, however, in his earliest engines he demonstrated the possibility of working with a pressure of 500 lbs. per sq. in., and successfully overcame the difficulties connected therewith, in his later plants he usually employed a boiler pressure of 300 lbs. per sq. in. reduced to 250 or 200 lbs. at the engine. The models, which represent an engine and boiler erected at a London factory about 1883, illustrate generally the arrangements he used both for land and marine work.

The engine is of the inverted three-stage expansion type, with single-acting high and intermediate pressure cylinders placed vertically one over the other, and a double-acting low pressure cylinder by their side, the two piston rods being connected to a crank shaft below having cranks at right angles. The high and intermediate pressure cylinders have tappet valves, and the low pressure one a piston valve, and all are driven by eccentrics on the shaft. The whole of the steam is first admitted to the top of the high pressure cylinder, so that its contact with the gland packing is avoided, and after performing the down stroke and expanding, it passes to the under side of the intermediate piston, where it further expands while performing the up stroke; it then passes to the upper end of this cylinder, which space acts as a receiver, and from thence to the double-acting low pressure cylinder,

in which it does further work by expansion before being discharged into the condenser (not shown). The cylinders are all jacketed with coiled wrought iron tubes, cast in the walls and supplied with steam direct from the boiler, while the water from the jackets is delivered into the hot well. A vertical air pump is employed; the horizontal circulating and feed pumps are driven from an eccentric which has an external controlling-rod.

The boiler is of the water-tube type, being formed of wrought iron tubes 2·25 in. internal diam., ·375 in. thick and 4·6 ft. long, closed at the ends by welding and connected by small vertical tubes ·875 in. inside diam. and ·22 in. thick. The firebox is formed of a number of these tubes, bent to rectangular shape, placed one over another 1·75 in. apart and connected by numerous small vertical tubes. The body of the boiler is made up of a number of vertical sections, composed of horizontal tubes connected at each end by small vertical ones, and these sections are connected at both ends with the top tube of the firebox and a steam collecting drum above. The whole arrangement of tubes is surrounded by a double casing of sheet iron, filled between with vegetable black to prevent loss of heat. The joints were all made by screwing the small tubes into the large ones, and are caulked till tight under a hydraulic test of 2,000 lbs. per sq. in. The feed water enters at the bottom tube of the firebox, and the water level is half way up the body.

To obviate incrustation it was found necessary to use distilled water; the small proportion not recovered from the condenser was made up from a distilling plant. For the same reason no oil was used in the cylinders, the pistons being packed with rings of an alloy which worked without any lubricant. Owing to the high pressure carried, the water gauges used consisted of mica plates clamped in metal frames. It is stated that one of these boilers when working at 500 lbs. per sq. in. evaporated 10·75 lbs. of water per lb. of coal.

One of the later examples of Perkins' system was the machinery of the yacht "Anthracite," a vessel of 94 tons, built in 1878. The cylinders were 7·75 in., 15·8 in. and 22·8 in. diam., by 15 in. stroke, while the boiler, which contained 147 tubes, had a heating surface of 633 sq. ft. and a grate area of 15 sq. ft.; the total weight of engine and boiler was 25 tons. At a test by Sir F. Bramwell, the engine indicated 80·5 H.P. at 130 revs. per min., with an estimated steam consumption of 18 lbs. per indicated H.P. per hour; the coal consumption was 1·8 lbs. per indicated H.P. per hour, but it is stated that in some cases this was reduced to less than 1·5 lbs.

81. Vertical engine (working). Maudslay Collection, 1900. M.3126.

This single cylinder pedestal engine was made by Messrs. Maudslay, Sons & Field for driving their collection of models at the 1862 Exhibition.

The cylinder is 4·1 in. diam. by 4·5 in. stroke, and is covered by a polished gun-metal case, leaving an air jacket between it and the cylinder. The guides are cylindrical bars, and the main crank-shaft bearings are carried by the pedestal. The steam is distributed by a short D slide-valve, driven by a single eccentric, which also works the feed pumps. The condenser and hot-well are arranged in the base, within which is also a vertical air-pump driven by an additional crank

in the crank-shaft. The speed is regulated by a gut-driven Watt governor, carried on the top of the cylinder casing and controlling the steam supply by a disc throttle valve. The feed delivery pipe is fitted with a weighted relief valve, so that when the feed pipe of the boiler is closed the water pumped can return to the hot-well.

82. Model of horizontal steam engine. (Scale 1 : 6.) Made by J. B. Jordan, Esq., 1865. M.2762.

This form of high-pressure engine was designed by Mr. Jordan, and used in the Clunes Gold Mines, Australia, for driving stamps.

It has a cast-iron bed, supporting the cylinder and guides, together with two bearings of the crank-shaft. Two equal fly-wheels are provided and are intended to be used as travelling wheels in conveying the engine to its destination, a temporary fore carriage being arranged under the cylinder end for the journey.

83. Safety steam motor. Lent by Messrs. Hathorn, Davey and Co., 1888. M.1909.

This combined arrangement of boiler and condensing steam engine was patented by Mr. H. Davey in 1884 and introduced as a domestic motor, since owing to the boiler working at atmospheric pressure no explosion is possible through neglect or unskilled attendance.

The steam cylinder is double-acting, and is arranged vertically within the steam space of the boiler; the steam is distributed by a slide valve driven by an eccentric on the crank-shaft, and the supply is controlled by a throttle valve connected with a centrifugal governor.

The furnace, boiler, and surface condenser are all formed in one casting, and the firebox is crossed by a deep water pocket. The level of the water within the boiler is visible through a glass window in a feed box on the side, which contains a copper float that automatically admits water as required.

The surface condenser is provided with vertical tubes, with the cooling water, which may be stored in the containing casing or in a detached tank, circulating outside them; it is cleared by an air pump of the vertical plunger type driven by an overhanging crank-pin on the fly-wheel shaft. It is stated that the consumption of coke is about 6 lbs. per H.P. per hour.

84. Drawing of double-acting steam engine. Contributed by G. Cawley, Esq., 1895. M.2750.

This shows a form of self-contained reciprocating engine introduced by Mr. Cawley.

The piston is of exceptional length, being two single-acting pistons cast together; the connecting member contains a transverse slot in which works a block encircling the crank-pin. The crank is of the bent type, and, with the block, is got into position through the side of the cylinder by an opening that is closed by a cover which contains one of the crank-shaft bearings. Steam is distributed by a rotating slide valve attached to the inner end of the crank-shaft. This example was designed to work suspended, and has its steam or compressed air supplied through a flexible pipe.

85. Diagram model of double-cylinder engine. Presented by the Institution of Civil Engineers, 1868. M.1086.

This illustrates a type of engine in which dead centres are avoided, although only one crank is employed. The device was patented in 1839 by Elijah Galloway, but was not practically used until considerably later (*see* Nos. 86 and 87). Two vertical simple cylinders are placed side by side, with the crank-shaft between them, and the piston-rods are connected by return links with the ends of the base of a triangular frame, the apex of which embraces the crank-pin, while the middle point of the base is constrained to move in a vertical line.

86. Drawings of double cylinder engines. (Scale 1 : 24.) Presented by J. Bernays, Esq., 1906. M.3443.

This compact form of engine (*see* No. 85) was re-invented by Mr. Bernays in 1874 with a simple and efficient valve gear, but built only to a limited extent; it has, however, since been used for both stationary and marine engines (*see* No. 87).

The arrangement consists of two vertical cylinders, which may be compounded, placed side by side with the crank-shaft above or between them. The piston-rod ends are connected by links with the ends of the base of a triangular frame, the apex of which embraces the crank pin, while the middle point of the base is guided in a straight line. The valve gear consists of a single eccentric, the strap of which has two connecting pins forming the corners of the base of a similar triangle which is controlled in the same way as the other triangle; each of the pins drives one valve.

One of the designs shown is for a compound mill engine having cylinders 30 in. and 45 in. diam. by 50 in. stroke, to indicate 500 H.P. at 45 revs. per min. with a steam pressure of 50 lbs. per sq. in. It has a Meyer expansion valve on the high pressure cylinder and the air pump is driven by a lever from the middle of the triangle base. The other design represents a blowing engine having two steam cylinders 30 in. diam. and two air cylinders 72 in. diam., the common stroke being 70 in. The air cylinders are placed vertically below the steam cylinders and there is very little framework. In both designs cross-head guides are dispensed with on account of the small obliquity of the connecting-rod links.

87. Double-cylinder engine (working). Made by Messrs. J. Musgrave and Sons, 1893. Plate II., No. 4. M.2532.

This is a small example of an engine differing only slightly from the preceding (Nos. 85 and 86).

Two cylinders, arranged side by side, have a common connecting-rod in the form of a triangle, the apex of which encloses the pin of the overhanging crank. The two other corners of the triangle are, by very short links, connected respectively with the two piston-rods, the crossheads of which slide in ordinary guides. From the middle of the top of the triangle two bridle rods couple the connecting-rod to a stationary centre on the side of the framing, and so restrict the movement and close the chain. The valves are in the form of cylindrical slides, and receive their motion from a common eccentric.

The example has 3 in. cylinders, with 4 in. stroke, and is intended to run at 300 revs. per min., when it will indicate about 3 H.P.

88. **Double-cylinder diagonal engine (working). Lent by R. Laybourne, Esq., 1896. M.2957.**

This represents an arrangement of engine patented by Mr. Laybourne in 1879. There are two diagonal cylinders acting on a single overhanging crank-pin; the guides for the crossheads are formed on the front covers of the cylinders. The slide valves are driven by a single pin, projecting from a block that is fixed in a slot formed on a return crank keyed to the crank-pin. When the block is at one extremity of the slot the valves work as in forward gear, while when at the other extremity, they secure backward running. The block is moved in its slot for reversing by worm and pinion gear, engaging in a rack fixed in the slot; this gear is adjusted by a small hand-wheel which, if held while the engine is running, brings the valves in mid-gear, and then when rotated moves them into the desired position.

89. Three-cylinder engine (working). Lent by P. Brotherhood, Esq., 1888. M.1924.

This type of steam engine is designed for conditions requiring a high speed and great compactness in the mechanism, and is largely used for driving dynamos and fans, also the propellers of the Whitehead torpedo—in this latter case using compressed air.

The three cylinders are single-acting, and arranged at 120 deg. round the crank-shaft. The connecting-rods, which work on a common crank-pin, have spherical small ends, upon which fit pistons fitted with metallic packing, there being no piston-rods. The cylinders being single-acting, there is no reversal of stress in the connecting-rods, so that slackness in the connecting-rod brasses does not cause a heavy knock, as would be the case in a double-acting engine—a circumstance which is conducive to quiet working at high speeds. The crank chamber is closed, and retains a quantity of lubricant—an arrangement which prevents the dust and grit from getting into the working parts, and also economises oil. The crank is of the overhanging type, with a counterbalance weight, and the pin drives a small crank arm connected with the valve gear. Steam is distributed to the cylinders by three piston-valves driven by a crank-pin, the valve motion for each cylinder being equivalent to that in an ordinary engine.

The governor, which is beyond the valve gear and enclosed in a removable cover, controls a small throttle valve of the piston type, and is loaded by a spring, which can be adjusted by an external hand wheel, so that the speed of the engine can be varied while running.

This example has cylinders 3 in. diam. by 4 in. stroke, and indicates 5 H.P. when running at 600 revs. per min. It is shown driven by power, with some of the covers removed so as to render the internal construction visible.

90. **Model of horizontal steam engine (working). (Scale 1 : 4.) Lent by Messrs. R. Hornsby and Sons, 1885. M.1625.**

This represents a high pressure engine, with a steam-jacketed cylinder supported throughout its length on a cast iron bed. The guides are cast with the bed and bored out, the crank-pin is attached to an overhanging crank-plate, and the outer end of the crank-shaft is carried by an independent bearing. The engine is fitted with a governor gear

that automatically adjusts the degree of expansion to the work being done. On the crank-shaft are three eccentrics, but one of these is solely used for working the feed pump. The others drive the main slide valve and the "back cut-off" or expansion valve. The travel of the expansion valve is determined by the position of a block in a rocking link, and this position is adjusted by the governor. When the governor rises it rotates the sheave of a small eccentric connected with it, and by this means moves the block along the link; as an eccentric is a non-reversible means of transmitting motion it is here introduced to prevent pressure from the link interfering with the action of the governor. The cylinder is 12·25 in. diam., by 22 in. stroke; when the engine is supplied with steam at 60 lbs. pressure and is making 95 revs. per min., it indicates 50 H.P.; the same design is followed for engines with cylinders up to 22 in. diam. by 40 in. stroke indicating 185 H.P.

91. Armington-Sims engine. Made by Messrs. Greenwood and Batley, 1889. M.2261.

This is an example of a high-speed horizontal engine of American design. The cylinder, which is 5 in. diam. by 7 in. stroke, is overhung and is finished externally by polished metal lagging covering the flanges as well as the usual non-conducting felt. The crank is formed with two counterbalanced discs, and there are also two fly-wheels, while the crank-shaft has exceptionally long bearings; the crank race is, moreover, enclosed by a cast-iron box, which retains any oil thrown off, and also carries the crank-pin lubricator, these various arrangements being resorted to on account of the high speed employed. The slide-valve is of the piston type, with the steam space in the middle, as was usual in the early long D valves; it is driven, through a rocking shaft, by an eccentric of variable throw within one of the fly-wheels. The governor, which is arranged within this fly-wheel, consists of two heavy swinging levers pinned to opposite arms of the fly-wheel, and pulled inward by helical springs. When the levers swing outward, through centrifugal action, they turn the main eccentric and also an eccentric carrying it, moving them in opposite directions, so that the main eccentric is shifted along an approximately straight line, the cut-off being thereby altered while the lead remains nearly constant.

92. Model of engine with "Corliss" valve gear. (Scale 1 : 6.) Made by Messrs. T. and C. J. Coates, from drawings supplied by Messrs. J. Musgrave and Sons, 1898. Plate II., No. 5. M.3015.

The horizontal engine represented was made by Messrs. Musgrave for driving a jute mill in Calcutta; its cylinder is 19 in. diameter by 36 in. stroke, and the fly-wheel, which is 12 ft. in diam., weighs 5·75 tons. The power is transmitted from the fly-wheel by eleven ropes 1·25 in. diam., which drive the line shafting of the various floors of the factory. The crank-shaft neck is 7·5 in. diam. by 15 in. long, and its bearing is composed of four brasses which can be separately adjusted; the outer bearing of this shaft is, however, of the simple two-piece type. When supplied with steam at 80 lbs. pressure and running at 80 revs. per min., the engine indicates 120 H.P.; if fitted with a condenser such an engine would economically exert 140 H.P.

The valve gear is of the "Corliss" type, and under the control of the governor; it alters the degree of expansion to meet the variations in the load, without the intervention of any throttle valve, and as usually set the speed does not vary more than 2·5 per cent. from no load to full load. The adjacent diagram shows how the point of "cut-off" changes with the slight alteration in the governor speeds.

The original Corliss valve gear was invented in 1849, by Mr. G. H. Corliss; not being an engineer, he experienced exceptional difficulty in getting his invention tried, but the results obtained ultimately led to its very extensive adoption; the first Corliss engine in Europe was that shown at the Paris Exhibition in 1867. The leading features of the arrangement are: the employment of separate steam and exhaust valves at each end of the cylinder, so that any alteration of the point at which steam is cut off can be made without interfering with the action of the exhaust valves; the valves are cylindrical, and each is capable of being separately adjusted. The two exhaust valves, which are at the bottom of the cylinder, are rocked by a single eccentric, while the two steam valves at the top are rocked by another eccentric. The steam eccentric swings an arm provided with a cylindrical end, upon which are two hardened steel plates; as the arm swings, these plates engage with similar plates attached to flat levers that proceed from cranks on the spindles of the two steam valves. As the arm reciprocates, the steam valves are alternately opened, but, at certain points, determined by the speed of the governor, the lever of the steam valve then opening slips off the corresponding driving plate; the valve then left free is rapidly turned into a closed position by the action of a helical spring. The spring is contained in a small cylinder provided with two air "dash-pots" by which the quick closing motion is quietly arrested; this sharp and automatically adjusted cut-off is now to be found in all modern "trip" gears.

The governor shown is of the high speed loaded type, and has its sensitiveness adjustable by means of a spring which is contained within the central weight; it is driven by three cotton ropes, but further to reduce the risk of the engine running away, through the governor stopping, an independent gear is fitted, so that if, after the engine has been started, the speed of the governor falls below a certain limit, a trigger releases a weighted lever which automatically stops the engine through its valve gear.

93. Model of vertical engine with Hackworth's valve gear (working). (Scale 1 : 6.) Made by Messrs. T. and C. J. Coates, from drawings supplied by the Brush Electrical Engineering Co., and Messrs. R. and W. Hawthorn, Leslie and Co., 1898. Plate III., No. 1. M.3039.

In its general arrangements and details this model represents one of the two-stage expansion engines supplied by the Brush Co. to the City Road electric light station. The cylinders are 13·25 in. and 23·5 in. diam. respectively, by 13·5 in. stroke, and are both steam jacketed. When supplied with steam at 100 lbs, pressure and delivering into a surface condenser the engine indicates 300 H.P. at 240 revs. per min. The fly-wheel is 7·5 ft. effective diam. and has 10 grooves for 1·25 in. diam. rope, by which a dynamo is driven.

The model deviates from the actual engine in that it does not show

the second valve chest to the high-pressure cylinder, the valve of which is driven by an eccentric on the crank-shaft controlled by a governor contained within a small fly-wheel. The high-pressure slide valves are of the double ported piston type, while the low-pressure valve is of the D-slide class; all have vertical balance cylinders above them. The exhaust valve of the high-pressure cylinder and the single valve of the low pressure are actuated by the arrangement of valve gear shown on the low-pressure portion of the model.

Both of the valve motions represented were patented in 1859 by Mr. J. W. Hackworth, of Darlington; the details of that on the high-pressure cylinder were arranged by Mr. F. C. Marshall, while those of the low pressure were devised by Mr. J. S. Raworth for an adjustable expansion arrangement only, reversal on electric lighting engines not being required. The Hackworth expansion and reversing gear consists of a single eccentric fixed to the shaft and opposite to the crank arm, from which the eccentric-rod proceeds in a direction approximately at right angles to the piston-rod. The end of the eccentric-rod is caused to move in a straight path, but one of adjustable inclination, while the valve-rod is attached to an intermediate point in the eccentric-rod. The motion directly derived from the eccentric gives the lead, which is constant, while that resulting from the sliding motion of the block in the inclined guide determines the cut-off and also the direction of running.

94. Sectional models of high-speed engine and dynamo (working). (Scale 1 : 4.) Received 1901. Plate III., No. 2. M.3205.

This type of engine was patented by Mr. P. W. Willans in 1884; with subsequent modifications it has been extensively adopted for the direct driving of dynamos. The engine is of the single-acting, two-stage expansion type with two high-pressure cylinders and two low-pressure ones, arranged with the high-pressures above, and all acting on a two-throw crank-shaft with the cranks 180 deg. apart.

The guide or crosshead for the small end of each connecting-rod is in the form of a trunk, working in a closed cylinder that acts as an air cushion: by this arrangement, combined with single-acting cylinders, the pressures on the brasses of the crank pins and shaft are never reversed, so that slack bearings are permissible without any knock resulting, to which feature the high working speed found practicable is chiefly due.

The steam distribution to each pair of tandem cylinders is effected by a long piston valve, extending through a trunk which serves as the piston rod of the two pistons while also acting internally as a valve by its passage through the metallic glands at the cylinder end; as the valve face is travelling with the piston, Mr. Willans in his patent of 1885 overcame the difficulty of steam distribution by forming his eccentric on the crank pin. The details of the arrangement of the valve gear and connecting-rods of this class of engine are shown more fully in the sectional motion diagram (*see* No. 214), since in the actual engine the whole of the crank chamber is completely enclosed, to retain the oil which forms a bath at the lower portion of this space.

The speed is regulated by a spring-loaded centrifugal governor, fixed on the outer end of the crank-shaft and adjustable by hand even while running. This governor moves an equilibrium piston-valve

which controls the admission of steam, but before reaching it the steam has to pass through a separator which removes priming water and any solid impurities.

95. Sectional model of high-speed engine (working). Received 1902. M.3262.

This represents a single-acting, inverted, two stage-expansion engine directly driving a large fan for mine ventilation (*see* No. 607), or other purposes. The engine was patented by Mr. N. Chandler in 1886–8, and subsequently improved; the two cylinders are arranged tandem fashion, with the high pressure above, so that there is a single piston rod acting downward upon a crank-shaft below, while the steam distribution is performed by two piston-valves similarly arranged and driven by a single eccentric. The cylinders are carried on a frame which contains guides for the piston and valve-rods, and the bearings for the crank-shaft; it also forms a closed chamber in which the oil is retained and distributed over the bearings by the motion of the revolving parts, access to it being, however, obtainable by side doors.

A special feature of this engine is the construction of the "sleeve" at the lower end of the valve, by which, while permitting the passage of the exhaust steam through itself, the valve can close the exhaust port, thus giving compression at the end of the stroke so as to absorb quietly the momentum of the moving parts and assist them on their return stroke. The action of the steam in the engine is as follows:—Boiler steam is admitted above the high-pressure piston, which then makes a down stroke; in the next up stroke this steam is allowed to pass to the under side of the high-pressure piston and into a receiver, from which, in the next down stroke, it is admitted to the top side of the low-pressure piston; from this, at about the completion of this down stroke, it is discharged into the exhaust pipe, or condenser, with which the lower side of the piston is in communication, except when the cushioning at the end of the stroke is taking place.

ROTARY ENGINES.

96. Drawing of Watt's rotary engine, with condenser. (Scale 1 : 16.) M.2557.

This is copied from the 1782 patent specification of James Watt, but there is no evidence that he ever constructed such an engine. The drawing shows a piston in the form of a closely-fitting radial arm projecting from an axial shaft in a cylinder. An abutment, arranged as a flap is hinged near a recess in the side of the cylinder, and swings while remaining in contact with the piston. Steam is admitted to the chamber on one side of the flap, and so causes an unbalanced pressure upon the radial arm.

The arrangement has been re-invented several times and has been worked out in a practical form (*see* No. 97).

97. Model of rotary engine (working). Presented by W. Routledge, Esq., 1869. M.1133.

This is a model of a simple form of rotary engine made and patented in 1818 by Joshua Routledge, whose name is well known in connection with the engineers' slide rule.

The piston revolves on a shaft passing through the centre of the cylinder casing. The flap or valve hinged to the casing, with its free end resting upon the piston, acts like the bottom of an ordinary engine cylinder. The steam inlet port is on one side of the hinge, and the exhaust port on the other. The admission of steam is controlled by a side valve, actuated by an eccentric on the fly-wheel shaft, so that the engine could work expansively, and the steam pressure resisting the lifting of the flap would also be greatly reduced, so diminishing the knock at this point, which, however, would always be a serious cause of trouble. The exhaust steam passes down to a jet condenser, provided with a supply of water from a containing tank, from which the injection is admitted through a regulating valve. The air pump which draws the air and water from the condenser and discharges them through a pipe passing out at the end of the tank, is a rotary machine constructed like the engine and driven by spur gearing from the fly-wheel shaft. Some efforts have been made to prevent leakage by forming grooves in the sides of the revolving piston and filling them with soft packing.

98. Model of a rotary engine (working). Presented by the Rev. Patrick Bell, LL.D., 1868. M.1097.

This engine shows one of the early attempts to obtain rotary motion from the pressure of steam without the intervention of a crank and connecting-rod; almost the same arrangement was proposed by Lord Armstrong in 1838 as a water motor, and a model subsequently constructed gave off 5 H.P. at 30 revs. per min., with an efficiency of 95 per cent.

A metal disc is secured to a horizontal axis carried in bearings, and the lower half of the disc is enclosed by a chamber of circular section having its axis a semi-circle. One end of this chamber is closed and provided with a pipe through which steam enters, the exhaust taking place through the open end. The disc is provided with three holes, each fitted with a circular plate turning on an axis radial to the disc, and these plates when set at right angles to the disc become pistons in the lower enclosing chamber. Toothed gearing is arranged to rotate these pistons into the plane of the disc on leaving the cylinder and back again immediately after entering, locking levers retaining them in position during the intervals. The steam pressure upon these pistons forces the disc round, but the engine is non-expansive, and although some provision for packing has been made, the leakage must have been considerable and the wear and tear excessive.

99. Model of a disc engine (working). Presented by R. B. Prosser, Esq., 1893. M.2521.

The disc engine was patented by Messrs. W. Taylor and H. Davies in 1836, and subsequently improved by others. In 1841 Messrs. Ransomes and Sims showed at Liverpool a Davies rotary engine of

5 H.P., the first portable engine on wheels. It drove a thrashing machine and was rendered self-propelling by pitch chains from the crank shaft to the travelling axle. A similar engine was applied with some success by Messrs. G. and J. Rennie to drive a screw propeller (*see* Marine Engineering Collection).

The chamber, which acts as a cylinder, is enclosed laterally by a spherical zone and endwise by a pair of cones. The piston is a circular disc fitting the interior of the zone round its edges, and having at its centre a ball which forms the joint on which it turns. From the ball, and perpendicular to the disc, projects a rod whose further end is socketed in a crank arm attached to the shaft to be driven. There is a fixed radial partition in the cylinder, and a corresponding slot in the disc permits of the requisite motion. By the disc and partition, together with the conical ends, the cylinder is divided at each instant into four spaces, two of which are enlarging while the other two are contracting as the crank revolves. The admission and eduction of the steam with regard to the various spaces is determined by a simple slide-valve. The volume swept through by the disc in each revolution is equal to twice the capacity of the vessel which acts as the cylinder, just as in the ordinary direct-acting engine.

100. Model of a rotary engine. Presented by John Hick, Esq., 1887. M.1840.

This is a wooden sectional model of a simple form of rotary engine patented by Mr. Hick in 1843. The working model in metal was made in the Museum in 1895.

A cylindrical drum revolves within a fixed cylindrical casing of considerably larger diameter. The drum is placed eccentrically within the casing so that the circumference of the revolving drum is in contact with the inside of the casing at one place. At one side of this line of contact is the port or passage for the admission of steam, and at the other side of it is the exhaust port. The circumference of the drum is divided longitudinally by two slots, fitted with cylindrical packings, through which two flaps or blades extend radially to the circumference of the casing. The inner ends of the blades are free to turn on a stud fixed centrally with the casing, and the exposed surface of these blades between the drum and the casing form pistons upon which the steam acts, and so causes them to revolve and carry round the drum.

101. Rotary engine (working). Lent by Messrs. Fielding and Platt, 1888. M.1911.

The action of this engine depends upon the oscillating motion which the cross of a universal joint has relative to the containing jaws when the system is rotated.

Two shafts are set at an angle of 165 deg. to each other and connected by a Hooke's joint; one serves as a pivot, the power being taken from the other. Four curved pistons are arranged on the cross-piece, two pointing towards one shaft and two towards the other, and on each shaft or jaw are formed two curved steam cylinders in which the curved pistons work. The steam enters and leaves the base of each cylinder through ports in the shaft, which forms a cylindrical valve working in the bearing as a seating.

On the revolution of the shafts the pistons reciprocate in their cylinders in much the same way as in an ordinary engine, and the valve arrangement is such that while each piston is receding from its cylinder the steam pressure is driving it, and during the in-stroke of each, its cylinder is in communication with the exhaust. There are thus four single-acting cylinders making each a double stroke for one revolution of the driving-shaft. The engine has no dead centres, and has been run at 1,000 revs. per min.

102. Tower's rotary engine with working model. Lent by Messrs. Heenan and Froude, 1889. M.2281.

A complete 6-in. engine, together with a wooden model, are shown, which illustrate the mode of action of the engine patented by Mr. Beauchamp Tower in 1879, and now known as the "spherical" engine because the working chamber is a complete sphere.

The mechanism is equivalent to a universal joint connecting two shafts inclined together at an angle of 135 deg. The cross-piece of the joint is filled in so as to form a circular piston, and the jaws or bows of the joint are filled in solid to the shape of a quarter of a sphere. The whole joint is enclosed in a spherical chamber, and it will be seen that the disc alternately approaches and recedes from the spherical segments to which it is attached, as the shafts rotate. Throughout each revolution there are two cavities simultaneously opening, and two closing—all four varying at the same mean rate, so that if steam is admitted into the enlarging cavities, and be permitted to exhaust from those that are closing, continuous rotation of the shafts is obtained. The rotation of the segments upon the surface of the sphere is utilised to distribute the steam—ports in the spherical surface being uncovered at the correct intervals by the moving segments.

The chambers obtained in this engine are each equal to a quarter of the volume of the sphere, and in one revolution the total volume passed is equal to that of the sphere. As the only reciprocation is that due to the swing of the disc, the engine is suited for high speeds, and, for the power given off, is very compact.

103. Rigg's revolving engine (working). Received 1892. M.2441.

This machine in its movements will be found to resemble an oscillating cylinder engine held by its crank-shaft, and performing its cycle by the revolution of the framing round the crank-shaft, and the cylinder round the crank-pin. The varying chamber of a reciprocating engine is thus obtained, while the inertia stresses due to the reciprocating parts are almost eliminated.

The engine has three single-acting cylinders, the long plunger pistons of which act outwardly upon three crank-pins, projecting from the face of any overhanging fly-wheel. The closed end of each cylinder is formed into an eye, and fits upon a stud or trunnion fixed to the engine bed. This stud is not on the same centre line as the fly-wheel shaft, so that in a complete revolution each piston makes a double stroke, of a length equal to twice this eccentricity. By carrying the stud on a sliding block so that the eccentricity can be varied, the stroke of the engine is rendered adjustable. The engine is reversed by sliding the stud into line with

the fly-wheel shaft and continuing the sliding so as to give the eccentricity on the opposite side. The passage of the working fluid to and from the cylinders takes place through the faces of the eyes at the cylinder ends, which are provided with ports. The fluid enters and leaves the engine by the block carrying the stationary stud, the face of the block forming a surface on which the nearest cylinder end revolves, and acting as a disc slide valve for the three cylinders. An adjacent sectional drawing shows clearly the details of this arrangement.

The engine can be worked by steam, air, or water, but the full advantage resulting from the variable stroke is only obtained when working with water, owing to the cylinder clearance increasing as the stroke is reduced. The ordinary speed of these engines is from 100 to 500 revs. per min. with water pressure of 750 lbs. per sq. in. When steam or compressed air is used, as many as 2,000 revs. per min. have been obtained.

104. Parsons steam turbine and high speed dynamo. Lent by the Hon. C. A. Parsons, F.R.S., 1890. Plate III., No. 3. M. 2319.

This is the original Parsons' steam turbine, made in 1884. It has worked for several years at 18,000 revs. per min., driving the dynamo which gives off 5 electrical H.P.

The motor consists of a series of parallel-flow turbines on the same shaft, the exhaust from the first being the supply for the second, and so on. By this arrangement the necessary velocity requisite for the efficient action of a steam turbine is greatly reduced. To allow for the increased volume of the steam as its pressure falls in passing through the machines, the proportions of the turbines alter as the final one is approached, the passages being enlarged and the pitch of the blades increased. A set of guide blades, with its corresponding rotating ring, forming one element of a later turbine, is shown separately beside the machine. End thrust is obviated by employing two equal series of turbines on the same spindle on each side of the central steam inlet, the exhaust taking place from each end equally. By this arrangement also, glands are avoided as the slight leakage through the bearings under the exhaust pressure is easily collected and occasions no loss. To prevent vibration the bearings throughout are not quite rigidly fixed to the main castings, but are permitted a slight movement between clamping washers, the alternate washers fitting the casting and clearing the outside of the bearing, and *vice versa*. The lubrication of the bearings is effected by a current of oil continually circulated by a small screw pump formed on the main shaft. In its course the oil passes through the hollow shaft of the dynamo so that it shall assist in cooling the armature and commutator.

The governing is performed by a cylindrical throttle valve actuated by a leather diaphragm, on one side of which the air pressure is reduced by a kind of fan attached to the main shaft. The exhausting action of the fan is partially neutralised by air entering through a pipe which leads from the top of the field magnet of the dynamo, where an iron arm turning on a vertical axis is, by the attraction of the field magnet, drawn round, against the action of a spring, into a position that causes its extremity to nearly close the entrance to the air pipe. By this arrangement the opening of the throttle valve is regulated by the centrifugal action of the fan and by the intensity of the

magnetic field, the control being partly mechanical and partly electrical.

The dynamo has a drum armature, but, owing to the high speed employed, only a few convolutions are required, which, being of large section, give a very low internal resistance. The commutator is built up of short gun-metal segments insulated with asbestos and dovetailed into steel rings. The machine is shunt-wound.

105. De Laval's steam turbine. Received 1896. Plate III., No. 4. M.2931.

This remarkable steam engine, invented and developed by Dr. Gustav de Laval, owes its success to the discovery by him, in 1889, of the fact that the velocity of the particles of an escaping jet of steam is increased by discharging through an expanding orifice, the conversion of the energy of the steam into momentum being so complete that, when applied to a form of Pelton wheel or impulse turbine (*see* No. 351), a high efficency is obtained. Without the expanding orifice, a simple steam jet turbine is one of the earliest forms of steam engine (*see* No. 3), and very uneconomical, but by the use of many such turbines in series an efficient engine is also obtained (*see* No. 104).

In the De Laval turbine, shown in section, the revolving wheel is built up of separate spokes that are clamped by side discs in a way that resists the severe centrifugal stress resulting from the immense velocity required, while at the same time permitting of well-finished and correctly shaped vanes being employed. The steam is directed, at an angle of 19 deg. with the plane of the wheel upon one side of it, through the expanding jet orifice, and after gliding round the concave faces of the vanes leaves the opposite face of the wheel with scarcely any dynamic energy remaining in it. The wheel is enclosed in a casing that communicates with the atmosphere or with a condenser.

To obtain an efficient turbine of this class it is, however, necessary that the velocity of the vanes should be nearly half that of the fluid of the impelling jet, a velocity so high (attaining 2,000 ft. per sec.) that special arrangements are necessary to render it possible. The wheel is fixed to one end of a long, flexible shaft, the other end of which is secured within a shaft carried in bearings, and in this way the wheel is allowed to determine its own axis of rotation in somewhat the same way as does a spinning top. The speed of the shaft is so high, however, that it is unsuited to any ordinary machinery, and is accordingly reduced in one step by helical gearing in the ratio of 10 : 1, the countershaft then running at a speed suited for the direct driving of small dynamos; for slower machinery the reduction can be further carried out by belting.

This example gave off 5·37 brake H.P. at 3,000 revs. per min. of the belt pulley, when supplied with steam at 82·5 lbs. pressure, and worked non-condensing.

A trial made in 1896 of a De Laval turbine for a New York central station, with a steam pressure of 147 lbs. per sq. in. and a vacuum of 25·7 in. is recorded to have shown a water consumption of 17·3 lbs. per brake H.P. per hour; the total power developed was 266 brake H.P., and the turbine disc made 9,000 revs. per min. The temperature of the inlet steam was 425 deg. C. and that of the discharge 40 deg. C.

106. Model of Curtis steam turbine (working). (Scale 1 : 6.) Made from drawings prepared in the Museum. Plate III., No. 5. M.3503.

This type of steam turbine was patented by Mr. C. G. Curtis in 1896 and subsequently developed. The model represents a turbine for driving a dynamo of 500 K.W. output, made by the General Electric Co., U.S.A., in 1904.

The turbine is of the impulse type, in which the steam is wholly expanded in diverging nozzles and then has its kinetic energy absorbed by the blades of revolving wheels. In order, however, to reduce the peripheral speed of the wheels to a practical value, two methods are simultaneously employed; firstly, the steam is expanded in two stages by two sets of nozzles, and secondly, each wheel has three sets of blades with intermediate fixed guide blades which redirect the steam, after passing through one set, on to the succeeding ones. This combined method gives a large reduction in the peripheral speed with a small number of wheels and blades.

The turbine has a vertical shaft with bearings at the top and bottom, the whole revolving load being carried by a water-jacketed, adjustable footstep bearing which is supplied with oil under pressure. The turbine casing consists of three parts, one above the other, a diaphragm being placed between the two upper parts dividing the interior into two chambers in each of which one of the triple wheels revolves. The lower casing forms a pedestal containing the footstep bearing and the exhaust outlet. The shaft is fitted with stuffing boxes where it passes through the casings and diaphragm. The first-stage nozzles, twelve in number, are fitted in the roof of the top chamber and the guide blades are supported by a removable door which is adjustable. The second-stage nozzles are fitted to the under-side of the diaphragm and are forty in number to allow for the increased volume of the steam. The guide blades occupy nearly the whole circumference and are fixed to the walls of the second casing, which is built up of four segments bolted together. Regulation is effected by a governor which closes or opens some of the first-stage nozzles; the second-stage nozzles are regulated by a large ring valve acting similarly, but operated by hand. The wheels are each built up of three steel discs, bolted together, and the blades are cut round the rims by special shaping machines; the passages thus formed are of constant width, but the depth, and also the blade angles, increase in accordance with the decreasing velocity of the steam. The guide blades are cut in the same way, in segments, and bolted to the casings. The dynamo is placed vertically above the turbine and directly coupled to it.

The turbine represented is designed for a steam pressure of 150 lbs. per sq. in., and a vacuum of 28 in.; it runs at 1,800 revs. per min. and develops 670 electrical H.P. It uses about 15 lbs. of saturated steam per H.P. hour, at full load, but with high superheat as low as 12 lbs. Machines of this type have been built to develop twenty times the above power.

LOCOMOTIVES.—I.

For Common Roads.

In this section are collected the machines for moving objects upon public roads by the agency of other than animal power; it does not include the vehicles hauled, as they are placed in the section devoted to transport appliances.

Self-propelled vehicles on roads can never attain the carrying capacity of those on the mechanically guided system of a railway, but their more extended range gives them an importance as transporting agents that will probably continue to increase. Many years, however, before the introduction of any form of railway locomotive, steam-propelled road carriages had been produced; but when Trevithick, in 1803, applied such a carriage to a tramway, the superior results gained on the special track caused the evolution of the railway locomotive to be much more rapid than the further development of the steam carriage.

The first practical horseless vehicle was the steam lorry built by Cugnot in 1763, which, in an improved form six years later, attained a speed of 2·25 miles per hour. Murdock in 1781 constructed several small and probably swift locomotive models, while in 1804 Trevithick produced the first steam-propelled road carriage that travelled faster than any horse-drawn vehicle; he built several other successful vehicles of the kind, as well as others specially suited for railways, in which connection his name is more generally known.

Sir Goldsworthy Gurney in 1827 constructed a steam coach, and three years later some of his coaches were successfully working a regular service between Gloucester and Cheltenham. Between 1827–34 Hancock, Dance, Church and others built some coaches, having an average speed of about 12 miles and a maximum of a little over 20 miles per hour, which plied as public vehicles in London and on some of the main coach roads. These successes were suddenly checked by an Act being passed by Parliament permitting the imposition of such heavy tolls on mechanically-propelled vehicles that in some cases the charges were twelve times those of a four-horse coach; at the same time, moreover, the development of the railway system with its higher speed absorbed so much general attention and enterprise, that by 1836 the steam road carriage was practically abandoned. In 1846–56, however, the heavy traction engine for agricultural and other purposes was introduced with great success, but its progress was similarly checked by a further Act limiting the speed of all mechanically-propelled vehicles to four miles per hour, even in the country, and requiring a man with a red flag to walk in front of the engine; these and other severe restrictions prevented any advance being made in this country in the construction of light road engines, although the steam traction engine developed continuously and became exceedingly useful.

On the Continent, however, Mons. Bollée introduced a steam

car in 1875, and MM. Dion and Bouton built a steam tricycle in 1882. In 1884 Mons. G. Daimler brought out his light and compact form of oil engine, which, in the following year, he fitted to a tricycle, and in 1885 Mons. C. Benz constructed his first oil-motor car. In 1894 Mons. L. Serpollet introduced his light steam carriage, and shortly afterwards some of these "automobiles" were imported into England, with the result that public attention was drawn to the existing restrictions, and in 1896 an Act was passed exempting from all these regulations any vehicle weighing less than 3 tons when empty. Since that time great progress has been made, the power and speed being considerably increased. The internal combustion engine using petrol as fuel is the motor chiefly used, and although this necessitates the use of change speed gearing, yet a large amount of flexibility and uniformity of turning movement can be secured by increasing the number of cylinders employed. Steam is generally preferred for the heavier class of commercial vehicles, while the use of liquid fuel has rendered successful its application to the lighter vehicles. Electric cars, while possessing several advantages, are practically confined to use in towns.

107. Model of Cugnot's steam traction engine. (Scale 1:5.) Made by MM. Regnard Frères, 1892. Plate IV., No. 1. M.2445.

Nicholas Joseph Cugnot, a French military engineer, in 1769 made a steam carriage somewhat like this model, which, travelling on a common road, and carrying four persons, attained a speed of 2·25 miles per hour, but, the boiler being insufficient, the supply of steam failed after running for twelve or fifteen minutes. These results, however, induced the French Government to order the construction of an engine for the transportation of artillery, which should be capable of carrying a load of about 4·5 tons and maintaining a speed of 2·25 miles per hour on level ground. The machine, of which the model shown is a copy, was made in 1770 by Brézin to Cugnot's designs, at a cost of £800, but was never tried, and is now preserved in the Conservatoire des Arts et Métiers at Paris. It consists of a heavy timber frame supported on three wheels and carrying in front an overhanging copper boiler. The front wheel has a broad, roughened tire, and is driven by two single-acting inverted vertical cylinders 13 in. diam. by 13 in. stroke. The two pistons are connected by a rocking beam, and their motion is transmitted to the driving axle by pawls acting on two modified and reversible ratchet wheels. The distribution of steam to the two cylinders is performed by a four-way cock actuated by a tappet motion. A seat is provided for the driver, who, by means of gearing, was to be able to steer the machine, the boiler and engines turning together as a fore-carriage through 15 deg. either way.

108. Murdock's locomotive model and drawing. Made in the Museum, 1894. Plate IV., No. 2. M.2413.

This is a copy of the original experimental model made by William Murdock in 1781–6, and now in the Birmingham Art Gallery. At the time, Murdock was at Redruth, erecting pumping engines for Messrs. Boulton & Watt, and in August, 1786, the firm's agent writes, "Wm.

"Murdock desires me to inform you that he has made a small engine "of ¾-in. diam. and 1½ in. stroke, that he has apply'd to a small carriage, "which answers amazingly." In September of the same year, Boulton, in writing to Watt, says that Murdock "had made his steam carriage "run a mile or two in Rivers's great room, making it carry the fire "shovel, poker, and tongs. William uses no separate valves, but uses "the valve piston, something like the 12-in. little engine at Soho, but "not quite." There is good evidence that, altogether, Murdock constructed three locomotives, the last of considerable size; but, under pressure from Boulton and Watt, he ultimately abandoned the invention.

The model is carried on three wheels, a steering wheel in front, and two 9·25 in. driving wheels, connected by a cranked axle behind. The rectangular boiler is of copper with brazed joints, and has an internal flue. A metal cup to hold spirit is secured below the flue or fire-box, and so forms the grate. The steam cylinder is ·75 in. diam. and double acting, with 2·125 in. stroke, and with its valve chest, is partly sunk into the boiler. A small safety valve is seated on the cylinder flange, and loaded by a spring finger to retain the necessary steam pressure. A beam is carried by a post at the front end of the model, and at the other is connected with the piston rod, while a connecting-rod is carried down to the crank-pin of the driving axle. The steam valve is moved by the beam at each end of the stroke, by a tappet action. The valve consists of two pistons connected by a tube, the space between the pistons being always open to the boiler; the exhaust from the lower end of the cylinder escapes through the connecting-tube. As the valve derives its motion from the beam, the engine will continue running in either direction when once started. Murdock placed rather too much of the weight on the driving wheels, and so to give stability and improve the steering added a weight over the steering wheel.

109. Original model of Trevithick's road locomotive. Woodcroft Bequest, 1903. Plate IV., No. 3. M.1835.

Richard Trevithick (born 1771, died 1833), who, with other Cornish engineers, had been endeavouring to construct some form of stationary engine that would not be an infringement of Watt's patent relating to the condensing engine, decided to abandon condensation altogether and by using steam of several atmospheres pressure to compensate for the portion of an atmosphere that he lost through having no condenser. The high-pressure engines which he thus introduced were soon adopted for light winding and for work where their compactness and simplicity were greatly in their favour. Having in this way gained some knowledge of the possibilities of this form of steam engine, he appears to have constructed in 1797 a working model of a road locomotive; but if, as is probable, he had seen Murdock's earlier work in this direction, the chief merit of his model consisted in the higher boiler pressure it could carry and in the results it produced.

The model here shown is believed to be the original one made by Trevithick, and to have been left at the works of Messrs. Whitehead and Co., of Manchester, who were manufacturing actual engines for him in 1804. It has a vertical double-acting cylinder, 1·55 in. diam. by 3·6 in. stroke, sunk in the boiler, and the piston-rod terminates in a guided cross-head, provided with connecting-rods reaching down to crank-pins in the two driving wheels, which are 4 in. diam.; there is, however, a spur wheel on this crank-shaft driving a pinion on the shaft of a fly-

wheel, which it rotates at three times its speed. In addition to its controlling action, the fly-wheel forms a convenient arrangement for moving the engine off a dead centre. The steam distribution to the cylinder is controlled by a four-way cock driven by a tappet motion from the crosshead.

The boiler is cylindrical with a removable end, and contains a large oval flue, closed at the further end and fitted with a cast iron block, which, after being heated in an external fire and replaced, supplies the heat required for generating steam ; a small safety valve is added which is held down by a plate spring, and the model is arranged with two expansible legs, by which the locomotive can be lifted off the ground and used as a stationary engine.

From the results obtained, Trevithick decided to construct the steam carriage, which he successfully tried on the roads at Camborne in 1801 ; it is believed to have weighed 1·5 tons, and to have had a speed of from 4 to 9 miles per hour. The general working was so satisfactory that, in 1802, Trevithick, and his cousin Andrew Vivian, patented a group of inventions relating to the high-pressure engine and its application to locomotion, while in the following year one of their steam carriages was working in the London streets. A modification of this engine, built by Trevithick, and successfully tried in 1804 on the Penydarran tramway, was the first form of railway locomotive (*see* No. 120).

110. Prints of Gurney's steam carriages. Presented by Miss A. J. Gurney, 1876. Received 1900 and 1904. M.1420 & 3331.

Sir Goldsworthy Gurney began his work on motor carriages in 1823, and in 1825 patented an arrangement of pushing struts or legs as a means of propulsion, together with a water-tube boiler, while by 1825–6 he had completed a carriage in which these features were embodied. In 1827 he patented a steam coach having six road wheels, the front pair, which the driver steered, being connected with the pole of an ordinary fore-carriage to control it ; this peculiar steering arrangement is stated to have been so satisfactory that it could be worked by a child. The two steam cylinders were arranged on perches below the coach body, and drove the rear wheels which were loose on their axles, the connection to one or both being by bolts in a circular plate on the outer ends of the axle and engaging in the nave ; a gab valve gear was used for reversing. Superheated steam was supplied by a boiler placed in the hind boot ; it was composed of U-shaped tubes about 1-in. bore, the lower legs of which formed the firebars and were connected with a water drum, while the upper ends opened into a steam drum ; the drums were further connected by a number of vertical pipes or down-comers. The draught was produced by a fan driven by a separate engine.

A coach embodying most of these features, including legs for hill-climbing, was built towards the end of 1827, and is represented in the top print. The rear wheels were 60 in. diam., the front ones 45 in., and the pilot wheels 36 in. Coke was the fuel employed, and sufficient for one stage was accommodated in the furnace, while 60 gals. of water were taken in a tank below the coach body. Steam separators were arranged behind the chimneys at the rear, and a steam jet, which was Gurney's invention, was used to force the draught. The vehicle weighed about 2 tons when empty, and would accommodate six passengers inside and twelve outside ; it is stated to have attained a speed of 15 miles per hour.

In one of the middle prints a succeeding carriage is represented ascending Highgate Hill in 1828; in it Gurney had abandoned the use of propelling legs.

The bottom print represents a steam drag or "tractor," constructed by Gurney in 1829 for hauling a carriage in which the passengers were conveyed. The general arrangement was similar to that of his coach, and the driving wheels were rotated by double arms keyed on the crank-shaft, and acting against pins projecting from the felloes, so as to give the necessary play. The boiler worked at a pressure of from 70 lbs. to 120 lbs. per sq. in., and the draught was produced by a steam jet, but it differed from the earlier form in having horizontal instead of vertical separators. The tractor was steered by a hand wheel, rotating a pinion gearing into a segmental rack. The print represents this steam carriage returning from Bath (August 12th, 1829), when it was met at Hounslow Barracks by the barouche of the Duke of Wellington, which was then attached in place of the trailer. The whole distance of 84 miles had been travelled in 9·3 hours, including stoppages, and the normal speed was 14 miles per hour.

Gurney's carriages were taken over and improved upon by Sir Charles Dance, who, from February to June, 1831, ran with them a regular service four times a day between Gloucester and Cheltenham (9 miles), as well as journeys upon other roads; the speed, including stoppages, was from 10 to 12 miles an hour. His enterprise was abruptly stopped by systematic obstruction of the roads, and by the imposition of excessive tolls, which in some cases formed one-half of the working expenses.

111. Print of Hancock's steam omnibus. Presented by George Ellis, Esq., 1858. M.2770.

Between 1827–38 Mr. Walter Hancock, of Stratford, built nine steam carriages of various types, all of which were mechanically successful, although ultimately abandoned. In 1832 he started a regular service of steam omnibuses between Paddington and the City, and the vehicle represented was built for this work in 1833.

One of the best of these steam carriages weighed about 3·5 tons and carried sixteen passengers; it accomplished a run from Stratford to Brighton in 8·5 hours, including 2·5 hours lost in stoppages. There were two vertical steam cylinders, 9 in. diam. by 12 in. stroke, driving a crank-shaft which, by pitch chain, was connected with driving wheels 48 in. diam., but the gearing virtually reduced them to 24 in., so that the tractive factor was 40. Steam was supplied by a sheet-flue boiler 2 ft. square and 3 ft. high, arranged over a grate which had a closed ash-pit and a fan draught.

112. Print of Church's steam carriage. Presented by R. B. Prosser, Esq., 1900. M.2962.

Mr. William Church in 1832-35 patented certain constructions of steam carriage, and introduced two forms of vertical boiler for supplying the steam; he also advocated the use of wheels with flexible arms and very broad but elastic rims. In 1832 his steam carriages ran between London and Birmingham, but the opening of the railway finally diverted the traffic. Two views are shown of his ornamental three-wheeled steam coach, and there is a perspective view of what is probably a proposed enlarged form of the vehicle, intended to carry fifty passengers.

113. Print of Squire and Maceroni's steam carriage. Presented by R. B. Prosser, Esq., 1900. M.2962.

Messrs. Squire and Maceroni in 1833 patented a form of water-tube boiler, consisting of a mass of vertical tubes, which formed also a fire-box shell; the lower or water ends of the tubes were connected, and the upper ends communicated with a steam drum. The drawing shows a carriage driven by two horizontal cylinders acting directly upon the cranked hind axle, which carries the driving wheels; forced draught is supplied by a fan worked from a pulley on one of the driving wheels. Several of these carriages were made, and they regularly ran at an average speed of 14 miles per hour, while the maximum was 20. The body was that of an open coach and seated eight passengers.

114. Print of Hills' steam carriage. Presented by R. B. Prosser, Esq., 1900. M.2962.

Between 1839–43 Mr. F. Hills patented several forms of multitubular and water-tube boilers with vertical shells or cases; he also described a steam coach fitted with such boilers. The cylinders were vertical and close to the boiler, which was behind with an overhanging platform for the stoker.

115. Locomotive for ice. (Scale 1 : 8.) Contributed by Nathaniel Grew, Esq., 1862. M.848.

This represents the engine "Rurik," built in 1861 by Messrs. Neilson and Co., at Glasgow, for use on the frozen Neva. For many winters the engine performed a regular passenger and mail service between St. Petersburg and Cronstadt; the train that it hauled consisted of three railway coaches mounted on sleigh irons. The track was a cleared one, provided with telegraph wires and signals; the locomotive, however, sometimes travelled into the country on the sleigh roads.

The engine has a locomotive boiler, with the feed water in a saddle tank above it, and a large footplate on which fuel is stored. There is a single pair of driving wheels 5 ft. diam., driven by a pair of cylinders 10 in. diam. by 22 in. stroke, giving a tractive power of 36·6 lbs. per pound of mean pressure in the cylinders. The connecting-rods drive an intermediate shaft, on which are the eccentrics, and this is connected with the drivers by coupling-rods. The front of the engine is carried on a sleigh with interposed springs, and steering is done from the front platform by worm gearing that turns the sleigh round a pivot near its end. In working trim the total weight is 12 tons, but the grip of the drivers is increased by steel spikes that project from their rims and enter the ice.

116. Model of a traction engine. (Scale 1 : 8.) Contributed by Messrs. Gardener and Mackintosh, 1865. M.716.

This engine, patented by Messrs. Longstaff and Pullan in 1859, has two inclined cylinders driving cranks at right angles. The crank-shaft by a two-speed gear is connected with the intermediate shaft, which, by overhanging pinions, gears into spur rings on the large travelling wheels. The intermediate shaft is arranged vertically over the driving wheels, so that the motion due to the action of the bearing springs shall not

interfere with the working of the spur gear. To distribute the weight when travelling on soft roads two small wheels are carried between the large drivers and are driven by teeth from their peripheries, but these additional bearing wheels can be raised above the road surface and out of gear when travelling on hard ground. Independent framing is employed to carry the mechanism so as to reduce the strains on the boiler.

Steering is done from a front platform, by a hand wheel, which, by pitch chain turns the fore carriage.

117. Model of a traction engine. (Scale 1 : 8.) Lent by Messrs. Aveling and Porter, 1889. M.2277.

This model is completed sufficiently to show the special features in the arrangement of the engine.

The single steam cylinder is jacketed and takes its steam from a dome formed on the upper portion of the jacket. The side plates of the fire-box are extended upward and backward, so that they can carry the bearings for the crank-shaft, counter-shaft, and the driving axle. The driving wheels, which carry about 85 per cent. of the total weight of the engine, are fitted with a bevel wheel compensating gear, for turning sharp curves. The engine is steered from the footplate by the hand-wheel shown.

118. Model of a steam road roller. (Scale 1 : 8.) Lent by Messrs. Aveling and Porter, 1899. M.3054.

This is a form of road locomotive in which, by the provision of wide-faced wheels completely covering the surface of the portion of the road passed, the loose road metal is levelled and at the same time consolidated and interlocked in a way that greatly conduces to its future durability, as well as immediately reduces the labour of draught-animals passing over it. The roller is also used for hauling a scarifier, for breaking up roads requiring repair. At other times it may be employed for driving stone-breaking machines or other duties requiring power.

The boiler is of the locomotive type and is prolonged in front by a casting that forms the base of the chimney and the housing for the top of the fork carrying the front rollers. This housing permits of a side-way swing of the fork, so that these rollers shall bear equally, and admits of the turning movement necessary in steering. The hind axle passes behind the fire-box and is connected with the driving wheels by independent removable pins.

The engine represented has a single steam cylinder, which is completely steam-jacketed, and is fitted with the usual link-motion reversing gear; the crank-shaft is carried by outside bearings secured to upward prolongations of the external fire-box sides, and by this extension the bearings of the two intermediate counter-shafts are also carried. There is a sliding sleeve on the first counter-shaft by which two different speeds of gearing can be obtained; in the intermediate position the crank-shaft is left free, for use when power is taken from the fly-wheel only. From the second counter-shaft the power is directly transmitted to a spur wheel, concentric with the driving axle. Projecting backward from the fire-box is a water tank, the sides of which extend upward so as to enclose the foot-plate and form also a coal bunker;

there is another water tank under the barrel of the boiler in front of the fire-box, and to this tank the steering mechanism is attached.

Steering is performed from the foot-plate by a hand-wheel which, by worm gearing, controls two chains connected with the fork of the front wheels; all of the road wheels or rollers are fitted with scrapers. A strap brake, forced on by a screw, is provided for use should occasion require exceptional retaining power. The boiler is fitted with a feed-pump on one side and an injector on the other.

These rollers are made in six sizes weighing from 6 to 20 tons and rolling a width of from 4·75 ft. to 8·25 ft.

119. Model of petrol motor car chassis (working). (Scale 1:4.) Made by Messrs. T. and C. J. Coates, from drawings prepared in the Museum, 1904. Plate IV., Nos. 4 & 5. M.3321.

This represents the complete framework and mechanism of a typical petrol-propelled car when a live driving axle is employed, the other most usual arrangement being that in which the axle is fast and the driving wheels are rotated by separate pitch chains. The motor is placed in front, with its crank-shaft on the longitudinal centre line and driving a central shaft by a friction clutch and change speed gear, through which the power is transmitted to the rear axle by a shaft and bevel gearing.

The motor is of the ordinary vertical type, with two cylinders each 100 mm. (3·9 in.) diameter by 132 mm. (5·2 in.) stroke, working on the Otto cycle and driving opposite cranks; when running at 900 revs. per min. it develops 10 H.P. The mixture of petrol vapour and air is derived from a float-feed carburetter, while the main air supply is heated by the exhaust gases; a centrifugal governor fixed to the half-speed or valve shaft controls the supply of the explosive mixture to the cylinders, but when extra power is required this mechanism may be thrown out of action. Ignition of the charge is performed by high tension electric sparks, timed by a rotary switch secured to the valve shaft, which pass between terminals arranged in the cylinder heads; the electricity is supplied by accumulators, through an induction coil, and the period of ignition is adjustable by moving the stationary switch contacts round the shaft. The cylinders and heads are cooled by jackets into which, by a rotary pump, water is forced and then sent through a radiator of gilled pipe placed on the front of the car, so that it may be cooled by the air before again entering the cylinder jackets.

The fly-wheel of the motor is recessed so as to form one member of a cone clutch, the other member of which is a leather-faced cone sliding freely on the squared end of a short first-motion shaft but pressed into driving contact by a spring whose action may be moderated or neutralised by a pedal.

The change-speed gear, which is of the Panhard type, consists of a sleeve provided with three spur wheels of different diameters and capable of being moved along a squared portion of the first-motion shaft, while parallel with, but below the sleeve, is the second motion-shaft, upon which are secured three corresponding wheels so spaced that by sliding the sleeve the transmission can be effected through either of the three gears. The position of the sleeve is controlled by a hand lever, and the gears are such as to give speeds of 8, 12 and 16 miles per hour when the motor is running at its normal governed speed

of 800 revs. per min.; at the lowest speed the motion of the car can be reversed by a pedal which introduces into the gear an intermediate wheel.

To allow for the difference in the lengths of the paths described by the driving wheels when the car is turning, these wheels are independently but simultaneously driven by the arrangement of differential gear introduced for the purpose by Roberts in 1832. This is carried out by making the rear axle in two lengths and securing a spur wheel to the inner end of each; these wheels are then enclosed in a box, or arm, which carries two pairs of wide-faced spur pinions loose on the spindles but gearing together and with the axle wheels. This gear box has fixed to it a bevel wheel, gearing with a pinion fixed to a short shaft carried by a stationary outer casing and driven from the second motion-shaft by a longitudinal shaft provided with "Hooke's" joints at its ends. When the car is moving in a straight course the wheels and pinions with their box revolve as a whole, but when describing a curve the driving wheels rotate at different speeds, owing to the pinions being free to revolve and thus allowing the outer wheel to go faster and the inner one slower than the mean speed. The axles of the driving wheels run in ball bearings and are enclosed in tubes screwed into the central gear casing, while the springs of the vehicle are attached to these tubes. The driving wheels are fitted with band brakes, applied by a lever which simultaneously releases the driving clutch, and there is a pedal brake on a drum on the second-motion shaft.

The car is steered by the front wheels, which are mounted on short independent swivelling axles, so connected that, when turning, the tracks of the four wheels have approximately the desired common centre. This device was proposed by Du Quet for some windmill carriages in 1714, was re-invented by Lenkensperger in 1818 for horse-drawn vehicles, and was patented in England by Ackermann: in 1832 it was applied by Redmund to a steam carriage. This arrangement avoids the tendency of a swivelling fore carriage to turn when one wheel meets an obstruction (which tendency is resisted by the pole in a horse-drawn vehicle), and also retains the stability of the vehicle owing to the steering wheels having a very small lateral movement. The axles of the front wheels are provided with horizontal arms by which they are coupled together and can be simultaneously but unequally steered, the correctness of the radiating action thus obtained depending upon the angles which the arms make with the planes of these wheels. The steering is performed by a hand-wheel mounted upon an inclined pillar and acting, by worm gear and a ball jointed rod, upon the arms of the axles of the front wheels. To reduce the steering resistance these axles are inclined downward so as to bring the contact points of the wheels with the road more nearly under the axle pivots.

The lubricators and the tank for petrol are carried on the dash board, and the handles for controlling the ignition and the governor are mounted on the steering pillar, while the accumulators are accommodated in the car body. The exhaust gases are discharged beneath the frame at the rear, through a silencer consisting of a cylindrical vessel packed with perforated plates.

The frame is built of wood strengthened by steel flitch plates and is attached to the axles by laminated springs; the engine and gear box are, however, carried on a separate frame constructed of channel bars and secured to the main frame. The wheels shown are of the artillery pattern, with wooden spokes held between metal flanges forming the

nave, and have wooden felloes provided with steel rims suitable for receiving pneumatic tires. The wheels throughout are 800 mm. (31·5 in.) diam., the wheel base is 2·1 m. (6·9 ft.) and the outside width of the track is 1·25 m. (4·04 ft.). The overall length of the car is 3·35 m. (11 ft.), its width 1·5 m. (5 ft.), and its weight loaded about 1 ton.

This model is so mounted in the case that the driving wheels and mechanism can be rotated by an external handle. The steering wheel can be manipulated by an external hand wheel so that the radiating action of the front axles may be investigated, and the mounting is such that when the front wheels are directed for a curved path the corresponding difference in the motions of the driving wheels results, so that the action of the differential gear can also be observed under various conditions.

LOCOMOTIVES.—II.

For Railways, etc.

In this section are grouped the engines employed in moving vehicles on special tracks, such as railways and tram-lines, by the agency of other than animal power; the different forms of track and of vehicles used upon them are placed in the sections devoted to land transport (*see* p. 326).

The rigid and confined track, as a means of lessening resistance with animal haulage, had been in course of gradual evolution for about 150 years before the use of mechanical motors upon it was attempted; since then both have developed concurrently.

Richard Trevithick, and his cousin Andrew Vivian, in 1802 patented a high-pressure steam road-carriage which, by some modifications, Trevithick, in 1804, adapted for working on a plateway. With one of these engines he succeeded in hauling a load of 25 tons on a line between Penydarran and Merthyr Tydvil, but owing to the weakness of the track the engine failed commercially, the damage done to the plates rendering it a more expensive agent than animal power; it had, however, smooth wheels, and discharged its steam into the chimney, the effect upon the fire being at the time appreciated. In 1808 Trevithick exhibited near what is now Euston Square, London, a steam locomotive which ran on a circular railway at a speed of 12 miles per hour, and the public were permitted to try the new mode of travel upon payment; the engine weighed 10 tons, and again the experiment failed financially through the weakness of the rails. Trevithick appears, however, to have made several similar tram engines for lines in various mining districts (*see* Nos. 120–1).

In spite of the fact that the adhesion of smooth wheels on rails had been demonstrated to be sufficient for a locomotive on certain tracks, the idea that something more was necessary was generally held, probably owing to the weakness of the plate-ways restricting the weight allowable per wheel to an amount that was frequently

seen to give insufficient grip. To avoid this difficulty John Blenkinsop, in 1811, patented a form of rack railway (*see* No. 683), which was laid between Middleton and Leeds in 1812, and between Kenton, Coxlodge and the Tyne in 1813. The engines employed were made by Messrs. Fenton, Murray, and Wood, and appear to have been the first commercially successful locomotives; they had, at the suggestion of Matthew Murray, two double-acting cylinders, instead of a single cylinder and fly-wheel as generally used by Trevithick, and, although the boilers had only single flues, these engines remained in use till 1831. In 1812 Messrs. W. and E. W. Chapman patented another form of locomotive in which simple adhesion was discarded, the machine propelling itself by toothed wheels gearing on the upper side with a long chain secured to the ends of the line; this was tried in 1813 at Heaton Colliery, but was soon abandoned.

In 1813 William Hedley, assisted by Christopher Blackett, the proprietor of Wylam Colliery, confirmed Trevithick's results as to the possibility of obtaining sufficient grip by adhesion, and, after some experimenting, constructed a locomotive with smooth wheels coupled together by gearing (*see* No. 124). The motor portion was an adaptation of the then established form of stationary engine, with vertical cylinders, tappet valve gear, and rocking beams as introduced by Newcomen and retained by Watt.

In 1814 George Stephenson constructed for the Killingworth Colliery his first locomotive, named "Blucher," which was a geared engine exhibiting no improvement on the work of his predecessors. In his second engine, however, he reintroduced the direct action of the connecting-rods on to the driving-wheels, as applied by Trevithick in 1808, and used coupling rods for connecting the wheels, although these were subsequently discarded for chain gearing. In this way a successful type of colliery locomotive was arrived at, and one which slowly proved its superiority to traction by animals where heavy loads were to be moved at a slow pace.

In 1825 the Stockton and Darlington Railway was opened for public traffic, the only engine on the line being, however, "Locomotion" (*see* No. 126). Although intended solely for the conveyance of minerals and goods, the financial success of this, the first public railway in the world, was considerably increased by the rapid development of passenger traffic. Other engines were soon required for the line, and in 1826 Messrs. Wilson & Co. built one embodying the use of four vertical cylinders, each pair working directly on to two cranks at right angles on a single axle; this improved feature, but with only a pair of cylinders, was retained by Timothy Hackworth when the engine was rebuilt in 1827 (*see* No. 127). In 1826 also Stephenson produced the "Experiment," a locomotive with two cylinders working directly on to one axle, and inclining downward, so making another advance towards the now almost universal arrangement of the engine.

The locomotive had not as yet exceeded the speed of the stage

coach, while its noise, smoke and jerky motion were defects that rendered it by no means popular, even with the unprejudiced; so much was this the case that in 1829, when the Liverpool and Manchester Railway was under construction, the directors were still undecided as to the best means of haulage. They offered accordingly a prize of £500 in order to find the best locomotive available and thus to be able to compare the new method with horse traction. The results attained by the "Rocket" (*see* No. 129) were such as to settle the question immediately in favour of steam locomotives; this historical engine was moreover the first conveyance that travelled faster than a racehorse, and thus foreshadowed the great future of the railway system.

Between 1830–5 the development of the steam locomotive in size and detail was most rapid; the "Northumbrian" of 1830 had a complete smoke-box, and the "Planet" of the same year had inside cylinders at the front end working directly on to a double-cranked rear-driving axle; engines with four and six wheels connected by external coupling rods had been in use since 1826, but the whole arrangement of the locomotive now rapidly settled into the almost universal form, as will be seen in the series of drawings Nos. 136, 139 & 140. The introduction, about this period, of improved valve gears gradually led to a reduction in the fuel consumption, but the full advantage of expansive working was not realised till the invention by Howe, in 1842, of the link motion (*see* No. 197) which rendered such working both simple and convenient.

The earliest attempt to arrange a locomotive as a compound engine was made about 1849, on the Eastern Counties Railway, when an ordinary goods engine had its valves so altered that the first cylinder cut off at about half stroke and then allowed its steam to expand in both cylinders. In 1876 Mons. A. Mallet introduced compounding on the Bayonne and Biarritz Railway, using one high and one low-pressure cylinder, which could, however, be worked simple if necessary. Mr. F. W. Webb commenced his work in compounding in 1878, by reducing the diameter of one of the cylinders of an ordinary engine and letting its exhaust pass into the other, while in 1881–2 he built the "Experiment" with two outside high-pressure cylinders driving the hind wheels and one low-pressure inside cylinder driving the front axle, there being no coupling rods (*see* No. 171). These engines have been successful, but in the latest type four cylinders are used owing to the perfect balancing thus attainable, coupling rods being, however, retained. Mr. A. von Borries built in 1880 some engines on the two-cylinder compound principle for the Hanoverian State Railways, and in 1885 Mr. T. W. Worsdell adopted the same arrangement on the Great Eastern Railway and subsequently on the North Eastern Railway (*see* No. 172); as the cylinders are side by side between the frames, the arrangement is one to which existing engines can be easily altered. In 1885 M. de Glehn introduced his four-cylinder compound engine having two inside high-pressure cylinders driving one axle and two outside low-pressure

cylinders driving a separate axle. M. du Bousquet modified this arrangement by interchanging the high and low-pressure cylinders and coupling the driving axles, thus originating the form now so much used on the Continent. In the system patented in 1889 by Mr. S. M. Vauclain of the Baldwin Works, U.S.A., and extensively adopted, there is a high-pressure cylinder and a low-pressure one beneath it, outside the frames on each side; the adjacent piston-rods are secured to a single crosshead, so that additional mechanism is dispensed with (*see* No. 176).

For working exceptionally steep inclines on ordinary railways the centre rail system, first proposed in 1830, has been tried (*see* No. 182), but such inclines are usually worked by locomotives having eight or ten coupled wheels of small diameter. On mountain railways, however, the gradients are such that the rack or cable haulage system must be adopted. The central ladder rack was first used in 1852 and subsequently developed by Mr. N. Riggenbach. The improved form of rack cut from flat bars, which has been used on many recent lines, was patented by Mr. R. Abt in 1882. Some of these rack lines are worked by electric locomotives.

Steam locomotives for tramways have been extensively used, sometimes assisted by reservoirs of compressed air; but now for all purposes requiring light trains at short intervals electric motors are being generally resorted to. The absence of waste gases gives the electric motor an overwhelming advantage where tunnels are general, while the actual efficiency of large steam engines, as employed at the electric generating stations, combined with the generally high efficiency of the dynamo, compensate for the losses resulting from the indirect way in which the energy derived from the coal consumed is applied to a train propelled by electric motors.

120. Original drawing of a Trevithick tram engine. (Scale 1 : 12.)

Photographs of a model of Trevithick's first tram engine. Presented by F. W. Webb, Esq., 1893. M.2553.

In 1803 Trevithick was building some of his high-pressure engines at the Penydarran Iron Works, when, at the suggestion of the proprietor, Mr. Samuel Homfray, he undertook to construct a steam locomotive to haul trucks on the tramway from the works to Merthyr Tydvil, a distance of about 9 miles. The engine was completed and tried in 1804, with the result that, when hauling five waggons and a useful load of 13 tons, its speed was about 5 miles per hour, with a coal consumption of about 25 lbs. per mile. Owing, however, to the frequent breakages of the cast-iron tram plates, the locomotive was soon stopped and used for stationary purposes in the ironworks.

The photographs shown were taken from a full-sized reproduction of this engine, and a portion of the plate-way, made by Mr. Webb, at Crewe, in 1893, as representing the first engine that ran on a confined track by the force of high-pressure steam and relied solely upon the adhesion of smooth wheels.

The locomotive had a single horizontal cylinder 8·25 in. diam. by 54 in. stroke, enclosed in the boiler, which was of cast iron, 6 ft. long

by 4·25 ft. diam., with a wrought iron furnace flue. The piston-rod crosshead was controlled by round guide-bars, and from it passed two return connecting-rods to the cranks on the fly-wheel shaft, on which was a spur wheel gearing into a large intermediate spur wheel carried by a stud on the side of the boiler; this wheel geared into a spur wheel on each of the two travelling axles, so that the adhesion due to the total weight of the engine was available for traction. The travelling wheels were 45 in. diam., and revolved at practically the same speed as the crank-shaft, so that the tractive effort per pound of mean steam pressure in the cylinder was about 40 lbs. The valve arrangement consisted of a four-way cock similar to that shown in No. 121 and worked by a tappet-rod from the crosshead; the exhaust was delivered into the chimney, where it was noticed that the waste heat rendered it invisible, and that it made the draught much stronger.

This engine weighed in working order 5 tons, so when Trevithick found it could deal with a load of 25 tons he considered it was unnecessarily powerful for the line, and therefore decided to build a smaller one, probably to this earlier design, which is identical with it in arrangement, but has a cylinder 4·75 in. diam. by 36 in. stroke and a tractive factor of 11; there is, however, no evidence that the lighter engine was ever constructed.

121. Original drawings of Trevithick's Newcastle railway locomotive. (Scales 1 : 16, 1 : 12, and 1 : 2.) Presented by Thomas Smith, Esq., 1873. M.1310.

It appears that Trevithick visited Newcastle in 1804 and arranged with John Whinfield, of Gateshead, for the manufacture of his locomotives in that district. Some of the drawings shown are dated 1804, and in May, 1805, an engine for Mr. Blackett, of Wylam, was completed; this was probably that shown in the shaded drawing in which the waggon-way has wooden rails and a gauge of 5 ft., as in use at Wylam till 1808. The arrangement of the engine is identical with that in the South Wales engine (*see* No. 120); the cylinder is 9 in. diam. by 36 in. stroke, and the boiler 4 ft. diam. by 6·6 ft. long; the road-wheels are 38 in. diam., but only revolve at four-fifths of the speed of the crank-shaft, so that the tractive factor was 48.

The rougher working drawings are probably from Trevithick's own hand, and amongst other details they show the "Regulating and throttle cocks for the engine." These two plug valves were combined in a single casing, in which the smaller plug served as a regulator for stopping the engine or controlling its speed, while the larger four-way plug was oscillated by a tappet gear so as to place the ends of the cylinder alternately in communication with the steam and exhaust connections, as now done by a slide valve. This locomotive was probably the first one with flanged wheels; it appears, however, to have been only a partial success, probably owing to the wooden rails being unequal to carrying its weight, which was about 4·5 tons.

122. Model of Blenkinsop locomotive. (Scale 1 : 12.) Lent by H. C. Embleton, Esq., 1904. M.3340.

This is the original model of one of four engines built by Messrs. Fenton, Murray and Wood, in 1812–13, to work on the rack railway

patented by John Blenkinsop in 1811 (*see* No. 683), and laid at the time between Leeds and the Middleton Colliery, a distance of 3·5 miles. This enterprise was the first in which the steam locomotive was used with financially successful results, and these engines remained at work for about eighteen years, until the boiler of one of them exploded. The rack railway has, moreover, survived, and is now being extensively adopted for mountain lines with exceptionally steep gradients.

The arrangement of the engines was an improvement on those built by Trevithick in having, at the suggestion of Matthew Murray, two cylinders working on separate shafts so connected that the cranks remain at right angles, thus avoiding any difficulty in starting.

Each engine had a cylindrical boiler, with a single internal furnace flue; in it were sunk two vertical cylinders 8 in. diam. by 20 in. stroke. Each piston-rod was controlled by vertical guides, while by return connecting-rods it drove parallel outside cranks on its crank-shaft. These two crank-shafts were connected by gearing with an intermediate shaft, upon one end of which was a large spur wheel gearing with the teeth of the rails (*see* No. 683). Steam was distributed by turning valves receiving motion through levers from eccentrics on the crank-shafts. The four carrying wheels were 35 in. diam.; the driving spur wheel was somewhat larger, and revolved at only half the speed of the crank-shaft, so that the tractive factor of the engine was about 67.

Blenkinsop stated that one of these engines weighed 5 tons, and cost £400, while it did the work of sixteen horses in twelve hours. It drew twenty-seven waggons, representing a load of 94 tons, at 3·5 miles an hour on the level, or 15 tons up a gradient of 1 in 18; lightly loaded, its speed was 10 miles an hour. The consumption of coal was 21·3 lbs., and of water 14·5 gallons, per train mile, so that each lb. of coal evaporated 6·7 lbs. of water.

123. Hedley's experimental model for testing adhesion. Presented by Thomas Hedley, Esq., 1862. M.340A.

Christopher Blackett, the proprietor of Wylam Colliery, had been searching since 1804 for some means of haulage better than animal power for conveying coal waggons over the 5 miles of track between his colliery and the wharves on the Tyne. He had found that Trevithick's locomotive did not succeed on his wooden rails, and, the then generally accepted explanation being that the smooth wheels gave insufficient grip, no further experiments were made in mechanical traction till 1812. In that year William Hedley, the viewer of Wylam, constructed the model shown, which has four road-wheels secured to two axles geared together by intermediate spur wheels, and capable of being rotated by external winch handles.

The results he obtained from the model led to the construction of a full-sized under-frame, with wheels similarly connected by gearing, and worked by men carried on it, so that the adhesion of all of the coupled wheels was available for tractive effort; this frame was subsequently fitted with a cast iron boiler and a single steam cylinder 6 in. diam., which drove the road-wheels through intermediate gearing. After repeated trials with this experimental engine the construction of an entirely new one was decided upon, chiefly because of the defective steaming capacity of the boiler.

124. "Puffing Billy" locomotive. Received 1865. Plate V., No. 1. M.340.

This engine was constructed at Wylam Colliery in 1813 by William Hedley, assisted by the enginewrights, one of whom, Timothy Hackworth, subsequently became locomotive superintendent of the Stockton and Darlington Railway. It worked between the colliery and the staithes at Lemington-on-Tyne.

The engine has two vertical steam-jacketed cylinders 9 in. diam. by 36 in. stroke, which, by grasshopper beams, transmit the power downward by connecting-rods to a shaft with overhanging cranks set at right angles. This shaft carries a spur wheel, which, by four other spur wheels, transmits the power to the four driving-wheels, each 39 in. diam., giving a tractive factor of 40, although originally the gearing made this factor 80. Steam is distributed by short D-slide valves worked by a tappet motion, and the places for the driver and fireman are at opposite ends of the boiler.

The boiler is a wrought iron cylinder with one egg-end and has an internal return furnace flue, as used by Trevithick; the grate area is 6 sq. ft., and the heating surface 77 sq. ft. The tender consists of a wooden frame supported on four wheels, and carrying a water tank and coal box.

Owing to the weakness of the plate-way, which was of cast iron (*see* No. 681), the engine was in 1815 rebuilt as an eight-wheeler, each group of four wheels being carried in a kind of bogie and two more wheels introduced into the gearing. It was altered back to four wheels about 1830 when the line was relaid with the cast iron edge rails now seen under it. These rails are of the double flanged fish-bellied type, with half-lap joints supported in chairs spiked to cross sleepers, and with a gauge of 5 ft.; each rail is 4 ft. long, and weighs 39 lbs. per yard.

The adjacent photographs show this engine at work in 1862, prior to its removal to South Kensington; also the sister engine, "Wylam Dilly," which worked till 1867, and is now preserved at the Edinburgh Museum. When first introduced the noise and smoke from these locomotives caused considerable irritation, so that legal opinion was taken on the subject (*see* adjacent frames) but the nuisance was subsequently abated by passing the exhaust steam into a quieting chamber before discharging it into the chimney.

125. Drawings of early locomotives employed on the Stockton and Darlington Railway, 1825–62. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1901. M.3089.

The Stockton and Darlington line—the first public railway in the world—was originally projected in 1817 by Edward Pease of Darlington, chiefly for the conveyance of coal from the Bishop Auckland collieries to the sea-board. The Bill authorising its construction, after being twice rejected, was passed in 1821; it provided for its being worked "by men and horses, or otherwise." In 1822 the line was re-surveyed and construction commenced; but in the following year, at the advice of George Stephenson, who made the final survey and had been appointed the engineer, a fresh Act was obtained, giving power to carry passengers as well as goods, and to employ locomotive engines.

The line commenced on the north bank of the Tees at Stockton, and proceeded in a westerly direction to Darlington and thence to the north-west terminus at Bishop Auckland, a distance of 24·66 miles; but there were four branches which brought up the total length to 36·25 miles, as shown on the adjacent ordnance map. The line was single, with passing places every quarter-mile; wrought iron fish-bellied rails weighing 28 lbs. per yard were used, and the gauge was 4 ft. 8 in.; but more clearance being required, this was increased by ·25 in. in 1840, and soon afterwards to the present standard. The cost per mile was about £9,000, and the ruling gradient was 1 in 104, but at Brusselton and Etherley there were inclines of nearly 1 in 33 which were worked by stationary engines.

The first rail was laid at Stockton in May, 1822, and the line was opened for traffic in September, 1825, by the engine "Locomotion," driven by George Stephenson and drawing a train of thirty-four vehicles forming a gross load of over ninety tons. The first regular passenger coach, the "Experiment," was put on in October, 1825, from which time both goods and passenger traffic rapidly increased; the identity of the undertaking became lost in 1863, owing to its being absorbed into the North Eastern Railway system. Reproductions of an advertisement and of a way-bill of the original line are shown in an adjacent section.

In the drawing the following ten of the early engines employed are represented, while a table gives particulars of their dimensions:—

No. 1, "Locomotion," was built in 1825 by Messrs. R. Stephenson and Co. This engine is fully described in connection with its model, No. 126; three similar engines, named "Hope," "Black Diamond" and "Diligence," were constructed for this line in 1826.

No. 5, "Stockton," built by Messrs. R. Wilson and Co. of Newcastle in 1826, had four vertical cylinders 6 in. diam. by 18 in. stroke with crossheads sliding in guides and each working, by a return connecting-rod, a driving wheel 48 in. diam., thus having a tractive factor of 27. The crank pins on each axle were at right angles, and each cylinder had its own valve gear and blast pipe; the boiler was 13 ft. long by 4·33 ft. diam. and had a single flue. This engine was unsatisfactory and, having been damaged in collision, portions of it were used in building the "Royal George" (*see* No. 127).

No. 6, "Experiment," built by Messrs. R. Stephenson and Co. in 1826, had inclined outside cylinders, 9 in. diam. by 24 in. stroke, acting directly on six coupled wheels 48 in. diam., thus having a tractive factor of 40. The boiler, 10 ft. long by 4 ft. diam., contained two through tubes 18 in. diam. each with its own grate; the exhaust was conveyed to the chimney by two blast pipes.

No. 5, re-named "Royal George." This engine was constructed at Shildon Works in 1827 by T. Hackworth, who utilised the boiler, funnel, and wheels of the "Stockton," but provided two new vertical cylinders with valve motions, and an additional pair of driving wheels. Further particulars of this engine are given in connection with its model, No. 127.

No. 9, "Globe," designed by T. Hackworth and built by Messrs. R. Stephenson and Co. in 1830, had horizontal inside cylinders, 11 in. diam. by 16 in. stroke, placed under the furnace, and four coupled driving wheels 60 in. diam., thus having a tractive factor of 32. The boiler was 10 ft. long by 3 ft. diam. and had a single flue with the grate in one end; on the top of the shell was a copper steam vessel in the form of a

globe, from which the engine received its name. This locomotive ran till 1839, when its boiler exploded.

No. 13, "Coronation," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1831, was one of thirteen engines built for mineral traffic; it had two vertical cylinders, 14·5 in. diam. by 16 in. stroke, overhanging at the front and driving, through an intermediate shaft, six coupled wheels 48 in. diam., thus having a tractive factor of 70. The boiler was 13 ft. long by 43 in. diam., and had one furnace tube 9 ft. long and 106 small tubes 4 ft. long.

No. 26, "Swift," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1836, had two vertical cylinders 11 in. diam. by 16 in. stroke working, through an intermediate shaft, the driving wheels, which were 48 in. diam., thus having a tractive factor of 40. The boiler was 9·6 ft. long and of oval section, 3 ft. wide by 4 ft. high; it contained a fire tube 4·6 ft. long, 29 in. diam., and 102 tubes 5 ft. long; its total heating surface was 256 sq. ft.

No. 27, "Arrow," built by T. Hackworth at Shildon in 1837, had inside cylinders 22 in. diam. by 9 in. stroke which, by rocking levers, drove cranks of 18 in. throw in the driving axle. The pair of driving wheels were 60 in. diam., giving a tractive factor of 72, and there were four other wheels 36 in. diam. The boiler had a rectangular fire-box of copper, and there were 133 tubes.

No. 43, "Sunbeam," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1837, was a four-wheeled engine with single drivers 60 in. diam. and horizontal inside cylinders 12 in. diam. by 18 in. stroke, giving a tractive factor of 43. It remained in use on passenger traffic till 1856.

No. 165, "Keswick," built by Messrs. R. Stephenson and Co. in 1862, was a large passenger engine with a leading bogie and four-coupled wheels 84·5 in. diam.; the cylinders were outside and 16 in. diam. by 24 in. stroke, thus giving a tractive factor of 73. The boiler had 1,053 sq. ft. of heating surface 12·75 sq. ft. of grate area, and there was a feed-water heating tank under the foot-plate.

126. Model of "Locomotion," engine No. 1 of the Stockton and Darlington Railway. (Scale 1 : 8.) Presented by Sir David Dale, Bart., 1896. Plate V., No. 2. M.2955.

The engine represented was built by Messrs. R. Stephenson and Co. in 1825, and ceased running in 1846, but is still preserved in working condition at Darlington by the North Eastern Railway Co. (*see* photograph).

The engine has two vertical cylinders 10 in. diam. by 24 in. stroke, each driving by side connecting-rods a pair of 48 in. diam. driving wheels. These wheels are of cast iron and are coupled together by external rods that maintain the driving crank-pins of the front and rear wheels at right angles. The valves are of the short D type, driven by rocking shafts which both receive their motion from a single eccentric on the leading axle, one shaft being rocked directly, and the other through a bell-crank lever. A platform runs along each side of the boiler, and from one of these the driver has control of the valve rods, for disengaging and reversing. The tractive power of this engine per lb. of mean pressure in the cylinders was 50 lbs., but the boiler pressure used was only 25 lbs. per sq. in. The exhaust steam from both cylinders was conveyed by two blast pipes into the chimney. The feed-water

was forced into the boiler by a single feed-pump 4 in. diam., driven by a lever from the front crosshead.

The boiler is 10 ft. long by 4 ft. diam., and has a single through flue 24 in. diam. and 10 ft. in length, delivering into the chimney, which is 17·5 in. diam.; the heating surface is about 60 sq. ft. The wheel base of the engine is 5·33 ft., and the weight in working order is 6·5 tons. A single safety valve is provided, loaded by a weighted lever.

The tender is built of timber, holds 15 cwt. of coal, and carries an iron tank containing 240 gals. of water. The tender, which also acts as a platform for the fireman, is carried on four cast-iron wheels 30 in. diam., has a wheel base of 4·75 ft., and when empty weighs 2·25 tons.

"Locomotion" is estimated to have been of about 20 H.P., and had a speed of eight miles per hour. The total weight of engine and tender in working order was about 10·5 tons.

The model is shown supported upon a model of the first railway bridge constructed by George Stephenson; it was erected at West Auckland in 1824, and was only replaced in 1901. The rails are of wrought iron, rolled to the fish-belly form and supported in chairs, which are shown resting on the timber flooring of the bridge.

127. Original model of the locomotive "Royal George" (1827). (Scale 1 : 16.) Received 1898. M.3040.

The "Stockton" was No. 5 locomotive on the Stockton and Darlington Railway, and was built in 1826 (*see* No. 125). The engine, however, proved so unsatisfactory that in 1827 Timothy Hackworth, the locomotive superintendent of the railway, obtained permission to rebuild it, and this model represents the reconstructed engine known as the "Royal George," which worked on the line from 1827 till 1842. The model was probably made to prove to the directors of the Stockton and Darlington Railway the soundness of Hackworth's design for the reconstruction of their original No. 5 engine.

Using the original boiler shell, which was 4·33 ft. diam. by 13 ft. long, Hackworth increased the heating surface by introducing into it the return flue of Trevithick (*see* No. 265), and as seen in Hedley's "Puffing Billy" (*see* No. 124); the wheels he increased to six in number, all coupled, while he used only two cylinders, 11 in. diam. by 20 in. stroke, arranged vertically over the trailing wheels. The load on the other wheels was distributed by long plate springs arranged as equalising levers.

The piston-rods are guided by parallel motions, by the levers of which a valve-shaft is continuously rotated; on this shaft are two loose eccentrics that form a valve motion and reversing gear.

The tractive power per lb. of mean steam pressure was 50 lbs., and the weight of the engine and tender was 15 tons; it could draw on the level thirty-two coal waggons weighing 130 tons at a speed of five miles per hour.

This engine and Stephenson's "Experiment" of 1826 were the first six-wheeled coupled engines ever built.

128. The "Agenoria" locomotive (1829). Presented by W. O. Foster, Esq., 1884. M.1620.

This engine was built by Messrs. Foster, Rastrick and Co. of Stourbridge for the Shutt End colliery railway at Kingswinford, Stafford-

shire, which it opened in June, 1829, and afterwards worked for over thirty years; it is almost identical with the "Stourbridge Lion," built by the same firm in 1828, and sent to America, where it was the first locomotive to run upon rails on that continent.

The engine has four coupled wheels, 48·75 in. diam., with a wheel base of 5·08 ft., and two vertical cylinders 8·5 in. diam. by 36 in. stroke, driving outside crank-pins set at right angles to one another and fixed in the rear wheels; the tractive factor is 53·4. The crossheads are guided by grasshopper parallel motions, and the connecting-rods are attached to intermediate points of the beams directly in front of the cylinders, thus reducing the crank throw to 27 in. The slide valves, of the common flat type, are driven by loose eccentrics whose motion is controlled by stops, fixed to the axle, which retain them in the correct positions for forward or backward motion; hand gear is provided for working the valves when reversing, and until the eccentrics attain their positions against the stops.

The boiler consists of a cylindrical barrel 4 ft. diam., and 10 ft. long formed with dished ends. The grate is contained in a furnace tube 29 in. diam., which branches into two flues, each 18 in. diam., through which the heated gases pass to a chamber at the forward end; this chamber is completely within the shell and it communicates with the chimney by a short vertical tube passing through the upper part of the barrel. The back-end plate carries the furnace and flues and is attached to the barrel by bolts, thus enabling the whole of the internal portion of the boiler to be easily removed for cleaning or repairs. The boiler is fitted with a dome surmounted by a spring-loaded safety-valve and was originally provided, in addition, with a "lock-up" safety valve; a single feed-pump is provided which is driven from one of the grasshopper beams. The exhaust steam is turned into the chimney, but, from the exceptional height of the latter, it is probable that this blast was not utilised to increase the draught; at the time the engine was built, great objections were raised to the noise of locomotives, and also to the smoke given off; these annoyances would be reduced by a quiet exhaust and a tall chimney. The grate area is 8·5 sq. ft., and the heating surface about 85 sq. ft.

The engine frames are of wood flitched with iron plates, which form also the axle-box guides; the boiler is secured to the frames at each end, while the cylinders and gear are fixed solely to the boiler. Springs are fitted to the front axle-boxes only, as the action of the vertical connecting-rods would have prevented their use over the rear axle; the axle-boxes were provided with mechanical lubricators, driven by toothed rings on the axles. The wheels are of cast iron with wrought iron tires, and the trailing pair are fitted with balance weights. The engine and tender in working order weighed 11 tons.

The engine is standing on some of the rails and chairs from the Shutt End line (*see* No. 688).

129. The "Rocket" locomotive (1829). Presented by Messrs. Thompson and Sons, 1862. Plate V., No. 4. M.341.

This celebrated engine was constructed by Messrs. R. Stephenson and Co. in 1829, to compete for the £500 prize offered by the directors of the Liverpool and Manchester Railway to the makers of the most successful locomotive competing at a trial to be held at Rainhill in October of that year; the particulars and conditions of the trial are given in No. 130.

The "Rocket" left Newcastle on September 12th, 1829, going part of the way by canal, and was delivered by waggon at Rainhill on October 2nd; the competition commenced on October 6th and continued for eight days. At that time the "Rocket" was painted yellow, relieved with black, while the chimney was white, and her greatest speed was 29 miles per hour; some years afterwards, however, she ran four miles in 4·5 minutes, or at the rate of 53 miles per hour. After the trial the "Rocket" was purchased by the Liverpool and Manchester Railway Co., and worked on the cutting between Chat Moss and Salford till the opening of the line on September 15th, 1830; during this period, however, the engine was improved by the addition of a smoke-box and the chimney was shortened. At the ceremony of opening the railway, this engine ran over and fatally injured the Right Hon. William Huskisson, then M.P. for Liverpool; this sad accident, however, drew great attention to the possibilities of travelling by steam, as George Stephenson took the injured gentleman to his destination, 15 miles away, at a speed of 36 miles per hour. The "Rocket" worked on the Liverpool and Manchester line till 1837, when it was removed to the Midgeholme Railway, near Carlisle, where it ceased running in 1844; it was brought to South Kensington in 1862.

The engine as it now exists differs in several respects from its form in 1829; the present fire-box sides and the chimney were fitted in 1862, while the cylinders were originally arranged at an inclination of 37 deg. with the horizontal, but they were altered within a year or two to their present inclination of 8 deg. The present trailing wheels are quite modern, but the original ones, which were also of cast-iron, were 34 in. diam., a size that the higher position of the cylinders rendered admissible. The engine is now standing on some of the original wrought iron rails of the Liverpool and Manchester line, presented by Mr. C. E. Stretton, in 1892 (*see* No. 690).

The engine has two cylinders, 8 in. diam. by 17 in. stroke, directly acting on driving wheels 56 in. diam., thus having a tractive power of 19·4 lbs. per lb. of mean steam pressure. The slide valves are worked by loose eccentrics, and there is a clutch arrangement, worked by a treadle, by which these eccentrics could be thrown out of gear when the engine was to be reversed, the valves at the time being independently worked by hand levers. The boiler has a cylindrical barrel 3 ft. 4 in. diam. by 6 ft. long, which was traversed by twenty-five copper tubes 3 in. diam. The fire-box was of copper, and was bolted on to the end of the barrel; it had at the top, back, and sides a 2·5 in. water space, while there was a fire-brick lining in front. The gases from the fire-box passed through the tubes into a small chamber at the base of the chimney, which served as a smoke-box; the area of the grate was 6 sq. ft., and the heating surface of the fire-box 20 sq. ft., owing to the introduction of the boiler tubes, the total heating surface was 138 sq. ft. Two copper pipes, 2·5 in. diam., connected the water space of the fire-box with that of the barrel, and two similar pipes placed at the top of the fire-box placed it in communication with the steam space of the barrel. The steam from the boiler was admitted to the cylinders by two copper pipes, leading from a regulating cock fixed above the fire-box and which received steam from a dome above the barrel through an internal pipe. The boiler pressure was limited to 50 lb. by two safety-valves 2·5 in. diam., one of which was loaded by a spring and lever, while the other was of the lock-up type covered by a dome of tin plate. The feed-water was introduced by a long-stroke pump worked directly from

the crosshead, while the exhaust steam was passed into the chimney by two pipes each fitted with a blast nozzle 1·5 in. diam., by which a draught equivalent to 3 in. of water pressure was ultimately obtained.

The framing of the engine is built up of 4 in. by 1 in. bar iron, and the weight is transmitted to the axle-boxes by plate springs. The engine weighed, when empty, 3·25 tons, and in working trim 4·25 tons, while the tender, which was a four-wheeled truck carrying a water barrel, weighed, when loaded, 3·2 tons, so that the total weight of the engine and tender in working condition was 7·45 tons. The wheel base was 7 ft. 2 in.

In 1886 Mr. F. W. Webb, of Crewe, constructed a full-size model of the "Rocket" as it appeared at Rainhill, and a photograph of this is also shown, together with a copy of a drawing prepared by Messrs. R. Stephenson and Co. from original records remaining in their possession, as well as other drawings.

130. Portions of the "Novelty" locomotive (1829). Presented by the Rainhill Gas and Water Co., 1904. M.3362.

The "Novelty" was built in 1829 in the short space of seven weeks by Messrs. J. Braithwaite and J. Ericsson to compete at Rainhill for the £500 prize offered by the Liverpool and Manchester Railway Co. During the trials it excited much interest, and it attained a speed of 31·9 miles per hour when running light, but owing to breakdowns was unable to fulfil the required tests and was, therefore, withdrawn from the competition. The engine was afterwards run experimentally on the line for some time, and in 1833 it was provided with new cylinders and boiler tubes by Mr. R. Daglish; it was then used on the St. Helens and Runcorn Gap Railway, after which its history is unknown. The original cylinders were, however, given to Mr. John Melling, who founded the engineering works at Rainhill, now occupied by the Gas and Water Co., where they remained in partial use until this one was presented to the Museum.

The parts exhibited are the complete cylinder with its crosshead and guide bars, the pedestal, the two side rods which connected the crosshead with the bell-cranks, and part of the valve-gear. The cylinder is 6 in. diam. by 12 in. stroke, and stands on a small table which forms the bottom cover; the guide bars are round rods tapped into the upper cylinder flange and also serve as cover bolts. The cylinder ports are formed in a separate brass casting screwed on to the cylinder and the valve chest is secured to this in a similar manner. The slide valve is driven by two links and a crosshead from levers on a rocking shaft below; this shaft is provided with a double-ended lever having a pin at each end, with which a gab rod, driven by a fixed eccentric on the crank axle, could engage; one pin gives the forward motion and the other the backward. The side rods and the valve rod have been altered at their lower ends to suit their subsequent uses.

131. Model of the "Novelty" locomotive (working). (Scale 1 : 8.) Made from drawings prepared in the Museum, with the assistance of information supplied by A. Braithwaite, Esq., 1905. Plate V., No. 3. M.3416.

This model represents the "Novelty" as it appeared at the Rainhill trials in 1829. The engine was carried on four equal wheels, 50 in.

diam., and had two vertical cylinders, 6 in. diam. by 12 in. stroke, which acted by means of bell-cranks and horizontal connecting rods on a crank shaft carrying the single driving wheels. The tractive factor was 8·64.

The boiler consisted of a vertical cylindrical chamber containing the fire-box, and a horizontal barrel, 13 in. diam. by 10 ft. in length, containing an internal flue or tube 31 ft. long, tapering from 4 in. diam. at the fire-box end to 3 in. diam. at the chimney; this flue was arranged as a coil of three limbs, and through it the hot gases passed from the top of the fire-box, descending to the chimney at the other end of the barrel. The ash pan was closed, and air for the fire was forced in below the grate by a blowing machine worked by one of the bell-cranks; there was no blast pipe, the exhaust steam from the cylinders escaping directly into the air. The coke was supplied to the grate down a central tube above the fire-box, which was closed by a pair of shutters to prevent its becoming a chimney. The grate was hinged and had an area of about 1·8 sq. ft.; the heating surface of the fire-box was about 9·5 sq. ft., and that of the tube about 33 sq. ft. The steam pressure was limited by a spring-loaded valve, and feed water was supplied by a force pump; the locomotive had no tender, but carried a water tank beneath the boiler, and coke in baskets on the platform.

The framing was of wood mounted on springs; the axle boxes and springs were tied together on each side by an iron bar, one end of which was connected with the frame by links. The wheels were of the suspension type patented in 1826 by Theodore Jones; each wheel had a hollow cast iron hub and a wrought iron rim provided with bosses having conical holes to receive the heads of the spokes. The wrought iron spokes were passed through the rim and alternately through holes at opposite ends of the hub, their inner ends being screwed and secured by inside nuts only, so that they could never be under compression. The total weight of the engine in working order was 3·85 tons.

132. The "Sans Pareil" locomotive (1829). Presented by John Hick, Esq., 1864. Plate V., No. 5. M.971.

This locomotive was made by Mr. Timothy Hackworth, the engine superintendent of the Stockton and Darlington line, to take part in the Rainhill competition in October, 1829, where, however, it proved unequal to the "Rocket," although in some respects it was a well-built engine. After the trial, however, the engine was purchased by the Liverpool and Manchester Railway Co., and used till 1831, when it was transferred to the Bolton and Leigh Railway. In 1837 the present cylinders, which are larger than the original ones, were substituted, and the wood-spoked wheels were replaced by wheels of cast-iron. In 1844 it was removed to Coppull Colliery, near Chorley, where one axle and pair of wheels were removed, and toothed gearing fitted to the other axle, in order to give motion to pumping and winding machinery. It worked in this way most satisfactorily till 1863, when, on the mine being exhausted, the engine was re-erected as a locomotive and presented to the Museum. The appearance of the engine in 1829 is shown by a copy of the original drawing (Scale 1 : 6).

The boiler has a cylindrical shell, with one end flat and the other dished, and an internal return flue, which projects beyond the boiler on the fire-grate side, and is enclosed in a water-jacket, thus considerably increasing the grate and heating surfaces. There are two

vertical cylinders acting directly downward on crank-pins in the driving wheels, which are, however, connected by coupling rods with the trailing wheels, and the engine is without springs. The valves are worked by two loose eccentrics on the driving axle driven by a clutch in one direction or by another clutch in the other direction when the engine is reversed, there being hand gear to control the valves when reversing in a similar way to that sometimes adopted in early marine engines. The exhaust steam was discharged into the funnel as a powerful blast, and, with the large flue employed, carried over much unconsumed fuel.

The cylinders were 7 in. diam., and 18 in. stroke, acting on four coupled wheels 4·5 ft. diam., giving a tractive power of 16·3 lbs. per lb. of mean steam pressure. The boiler had a grate area of 10 sq. ft. and a total heating surface of 90·3 sq. ft. The engine in working trim weighed 4·77 tons; the tender was similar to that of the "Rocket." Dimensioned drawings of the engine are shown.

The "Sans Pareil" is now standing on the original rails, as in the case of the "Rocket," with stone sleepers, which were about 20 in. square and 12 in. deep.

133. Drawing of the three locomotive engines which competed at Rainhill in 1829. (Scale 1 : 24.) Prepared in the Museum, 1892.
M.2500.

When the Liverpool and Manchester Railway was nearing completion it became necessary for the directors to determine upon the motive power to be employed, and, having received reports from their engineers favourable to the employment of locomotives, they offered in April, 1829, a premium of £500 for the engine which would best fulfil certain conditions, particulars of which are given on an adjacent lithograph.

The trials were commenced on October 6th, 1829, and Messrs. J. U. Rastrick, N. Wood, and J. Kennedy were appointed judges.

Five engines were entered for the competition, viz. :—

The "Rocket," by Robert Stephenson (*see* No. 129).

The "Novelty," by Messrs. J. Braithwaite and J. Ericsson (*see* Nos. 130–1).

The "Sans Pareil," by Timothy Hackworth (*see* No. 132).

The "Perseverance," by T. Burstall.

The "Cyclopede," by T. S. Brandreth (*see* No. 134).

The trials were conducted at Rainhill, on a level piece of the line, 1·75 miles in length, of which 220 yards at each end were allowed for starting and stopping. The competing engines were required to make ten double trips, going over the central 1·5 miles at full speed, which was to represent a journey from Manchester to Liverpool. Then a fresh supply of water and fuel could be taken up and the second ten trips performed, which represented the return journey, the average speed throughout to be not less than 10 miles per hour.

The first engine to be tried on October 8th was the "Rocket"; it weighed 4·25 tons and had a load of 12·75 tons attached to it. It completed the whole of the double journey at an average speed, over the central portion of the track, of 13·8 miles per hour, its maximum speed for one trip being 24·1 miles per hour.

The next, on October 10th, was the "Novelty," which, on account of its elegant appearance, was the popular favourite; it weighed 3·05

tons, and its load was 7·7 tons, but, after running 3·25 miles, it was stopped by a defective feed pipe. After being repaired it ran an unofficial trip at 19·4 miles per hour. On October 14th it was again brought out and ran about 6 miles, attaining a maximum speed of 16·1 miles per hour; then some of the boiler joints gave way, causing its withdrawal from the competition.

The "Sans Pareil" appeared before the judges on October 13th, when it was found to weigh 4·77 tons, and should therefore have been carried on six wheels. It was thus rendered ineligible to compete for the prize, but was allowed to take its trial. The load attached to it was 14·32 tons, but, after running 27·5 miles at an average speed, over the central portion of the track, of 13·95 miles per hour, and a maximum speed for one trip of 17·5 miles per hour, the feed pump broke down and ended the trial.

The "Perseverance," about which little is known save that it had a vertical boiler with small heating surface, was also tried, but only attained a speed of 4 or 5 miles per hour and was withdrawn, while the "Cyclopede," which was also found unsatisfactory, had a speed of 6 miles per hour.

The "Rocket," which was the only engine to complete the journeys and fulfil all the conditions, was therefore awarded the prize. These trials convinced the directors of the suitability of the locomotive as a means of haulage. The railway was completed and formally opened for public use on September 15th, 1830.

134. Model of Brandreth's "Cyclopede." (Scale 1 : 6.) Presented by Admiral Sir T. Brandreth, K.C.B., 1894. M.2576.

This model shows the machine patented in 1829 by Mr. T. S. Brandreth, and entered for competition at the Rainhill trials in the same year. It was a kind of horse velocipede, intended for use on railways, but as the speed attained was only 6 miles per hour the device was abandoned. The "Cyclopede," with its horse, weighed 3 tons; so that, in proportion to the power exerted, it was very heavy, and would require much more than one horse-power to drive it at any considerable speed. The machine was carried on four flanged wheels, which, by spur gearing, were driven by the endless apron or platform on which the horse walked. This apron was formed of boards 4 in. by 1·5 in., each fitted with end cleats which extended half-way across the adjacent boards, and so distributed the weight. The boards were secured to two endless ropes passing over return pulleys at each end; six intermediate pulleys supported the upper side of the apron, and four the lower or slack side.

The sketch shows the original arrangement of the complete machine; but in the model the apron has a slope of 1 in 13, so that the horse was compelled to walk, as the platform receded under the action of the weight of the animal. This form of horse gear is now used in some districts for driving agricultural machinery (*see* No. 342).

A photograph of a letter from Stephenson to Hackworth regarding the proposal is shown.

135. Lithograph of "William the Fourth" locomotive (1830). Presented by R. B. Prosser, Esq., 1901. M.2758.

This was one of two locomotives built in 1830 by Messrs. J. Braithwaite and J. Ericsson, under a contract with the Liverpool and Manchester Railway Co. They were to weigh less than 5 tons and to draw

a gross load of 40 tons at a speed of 15 miles per hour on a coal consumption of 5 lbs. per ton per mile; they proved failures, ho.,ever, owing to shortness of steam, and were not accepted.

The engines were of similar construction to the "Novelty" (*see* No. 131). They had four equal wheels 56·5 in. diam., and two vertical cylinders 12 in. diam. by 14 in. stroke. By means of bell-cranks and horizontal connecting-rods motion was given to a crank-shaft on which the single driving wheels were fixed. The tractive factor was 35·7. The boiler was larger than that of the "Novelty" and differed from it in the manner of producing the draught, the hot gases being exhausted by a fan placed at the end of the flue tube in the vase-shaped structure shown on the top of the steam chamber. The framework was carried on springs and Jones' patent suspension wheels, while fuel and water were carried on a separate tender.

136. Drawing of early locomotives built by Messrs. Robert Stephenson and Co., 1825–51. (Scale 1 : 24.) Prepared chiefly from tracings and particulars furnished by C. E. Stretton, Esq., 1898. M.2970.

The Forth Street works at Newcastle, on the south bank of the Tyne, were established in 1823 by Messrs. George Stephenson, Robert Stephenson, Edward Pease, and Thomas Richardson. The first order was received in 1824 for two engines for the Hetton Colliery Co.; these were of the same size and construction as the first engine represented on the sheet.

No. 3 was built in 1825, and is the famous No. 1 engine of the Stockton and Darlington Railway. It is now preserved at Bank Top, Darlington, while a model and full description of it are found elsewhere in this Museum (*see* No. 126).

No. 9, built in 1826, was a six-coupled goods engine, with two inclined outside cylinders, 9 in. diam. by 24 in. stroke, acting directly upon the crank-pins; the driving-wheels were 4 ft. diam., giving a tractive power per lb. of mean steam pressure in the cylinders of 40 lbs. The boiler had two grates and through furnace flues.

No. 12 was built in 1828, and delivered in January, 1829, to an American canal company. It was a four-wheeled engine, with coupled wheels 4 ft. diam., and two outside inclined cylinders 9 in. diam. by 24 in. stroke.

No. 19 was the famous "Rocket" (*see* No. 129), built in 1829, to the joint order of George and Robert Stephenson.

No. 20 was delivered in 1830 to the Canterbury and Whitstable Railway, now a portion of the South-Eastern system. The boiler was subsequently lengthened, and in this condition the engine is still preserved at Canterbury. It had four coupled wheels 4 ft. diam., driven by two outside inclined cylinders 10 in. diam. by 18 in. stroke, giving a tractive factor of 37. The boiler, which is subsequent to that of the "Rocket," had twenty-five tubes 3 in. diam. and a rectangular fire-box. An important feature in this engine is that the cylinders are at the forward end, an arrangement that has since been almost universally followed.

No. 29, delivered in October, 1830, to the Stockton and Darlington Railway, was a four-wheeled coupled engine, with the frames passing beneath the axles. There were two inside cylinders, 11 in. diam. by

16 in. stroke, placed beneath the smoke-box. The wheels were 5 ft. diam., and the total heating surface was 407 sq. ft.

In 1830–1 Robert Stephenson's partners retired, and he took complete control of the engine works, which he reconstructed. The thirty-seven locomotives already built are not included in the new books, which started with a fresh No. 1, that formed part of an order for three engines for the Stockton and Darlington Railway. The following numbers must therefore be increased by thirty-seven to give their true position in the output of the Forth Street works.

No. 25 was delivered in America in May, 1831. It is a four-wheeled coupled engine, with inside cylinders 9 in. diam. by 20 in. stroke, and wheels 4·5 ft. diam. The fire-box is circular in plan. This engine was renamed "John Bull," and is still preserved in working order.

No. 42 was delivered in America in April, 1833; it had a single pair of driving wheels at the back, 4·5 ft. diam. driven by two inside cylinders 9 in. diam. by 14 in. stroke. The front end of the engine was carried on a four-wheeled bogie.

The standard goods engines, built 1835–7, had inside cylinders 15 in. diam., 18 in. stroke, driving four coupled wheels 4·5 ft. diam., and there was a leading pair of smaller wheels; previously these additional wheels had been arranged on a trailing axle. The total heating surface was 571 sq. ft., the tractive factor was 75, and the weight of the engine in working order without tender 14·6 tons.

No. 150, "North Star," was delivered in 1837 to the Great Western Railway, and is famous as the first engine of that line, although not originally designed for it; the link motion shown was added subsequently. It had a pair of inside cylinders 16 in. diam. by 18 in. stroke, and single driving wheels 7 ft. diam., giving a tractive factor of 55. The heating surface was 850 sq. ft. and the grate area 11·76 sq. ft.

The engine "Folkestone," delivered to the South-Eastern Railway Co. in 1851, was constructed to a design by Mr. T. R. Crampton, and had a single driving axle behind the fire-box with wheels 6 ft. diam., while the front four wheels were 3·5 ft. diam. There was a pair of cylinders 15 in. diam. by 22 in. stroke, arranged under the smoke-box and working on a crank-shaft, from which, by outside cranks and coupling-rods, the motion was transmitted to the driving wheels. Several of these engines were built, and they attained high speeds, but in general work the arrangement was not satisfactory; they were afterwards all converted to the ordinary form with wheels upon the driving axles.

An adjacent lithograph (scale, 1 : 96) gives outlines of engines built between 1825 and 1885.

137. Original drawings of early locomotives. Lent by Messrs. Robert Stephenson and Co., Ltd., 1901. M.3201.

These are some original working drawings of locomotives built by this firm between 1827–34, for the Liverpool and Manchester and other railways. They include drawings of "Invicta," "Northumbrian," "Planet," "Patentee," and of link motion details, 1842; each has a short description attached.

138. Photographs of Tredegar locomotive. Received 1898. M.3021.

This engine, No. 16 in the books of Messrs. Robert Stephenson and Co., was constructed in 1829 for the Tredegar Iron Works. It was a

six-wheeled-coupled engine, used in hauling coal trucks, etc., on the Sirhowy tramway between Tredegar and Newport, and subsequently in conveying slag from the Tredegar furnaces to the cinder tips. The cylinders were 10·5 in. diam. by 20 in. stroke, and the driving wheels 42 in. diam., so that the tractive factor was 52.

In 1882 it was discarded, and some time later the upper photograph was taken; the lower two photographs are much more recent, and show the engine dismantled. Even the earlier photograph represents the engine much modified from its original construction, which externally resembled the "Experiment," shown on the sheet of drawings, No. 136.

139. **Drawing of early locomotives employed on the Liverpool and Manchester Railway, 1829–34. Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1895. M.2758.**

In this drawing eight examples selected from the first thirty-six locomotives used on this line between 1830–34 are shown, and the leading dimensions given, together with a section of the line.

The diagram shows the "Rocket" in its original state, with the cylinders acting downward at an angle of 37 deg., as they were at the Rainhill competition in October, 1829 (*see* No. 129).

The "Northumbrian," which was the finest engine at the opening of the line in September, 1830, very much resembled the "Rocket," as it now is, with its cylinders nearly horizontal.

The "Planet" showed a great change in the arrangement of the locomotive and one that has since become almost universal, the cylinders being placed inside and under the smoke-box. A peculiarity of the engine was that the frame passed below the driving axle.

In the "Mercury" the frame was above both axles, and nearly all the other features of the present locomotive are noticeable. This engine was, in December, 1833, converted into a six-wheeler, as shown in red lines.

The "Samson" had four equal wheels, coupled by external rods. On a cotton handkerchief printed in 1831 is represented the opposite side of this engine, showing a large hand-power feed pump, an arrangement that was for some years adopted to prevent delay should the engine-driven pump fail. The above five designs were all carried out by Messrs. R. Stephenson and Co., by January, 1831.

The "Liver," by Edward Bury (*see* No. 141) was a four-wheeled passenger engine, of a type that was afterwards extensively built by him, even after nearly all railways had adopted some form of six-wheeled engine.

The "Patentee," by Messrs. R. Stephenson and Co., in 1834 was a six-wheeled engine, with single drivers in the middle, and no flanges to them. It had a "steam" brake.

The "Swiftsure," by Messrs. Forrester & Co., in 1834, was an outside cylinder engine with single drivers. At the time it was constructed, however, it gave considerable trouble and dissatisfaction owing to the defective balancing of the reciprocating parts, and the extreme width between the cylinders.

140. **Drawing of the locomotives employed on the Leicester and Swannington Railway, 1832–46. Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1892. M.2479.**

The Leicester and Swannington Railway was commenced in 1830, and opened on July 17th, 1832, Robert Stephenson being the engineer.

The main line was 16 miles in length, but included two heavy inclines that could not be worked by locomotives. The Bagworth incline, 950 yards in length, with a gradient of 1 in 29, was worked by a rope, the loaded train from the colliery at the summit pulling up the empty one; but the Swannington incline, with a gradient of 1 in 17, was, and continues to be, worked by a stationary engine and rope. The remainder of the line had gradients of from 1 in 97 to level, and was worked by the engines illustrated. The gauge was 4 ft. 8·5 in., and the rails of wrought iron of the "fish-bellied" pattern, weighing 35 lbs. per yard. Since 1846 this railway has formed part of the Midland system.

Particulars are given of the whole ten engines employed; the "Goliath" and "Hercules," however, are not shown in the drawings, as they were almost identical with the "Samson." The rapid increase in power and heating surface will be seen to be remarkable if the "Comet" of 1832 is compared with the "Atlas" of less than two years later. The "Samson" was the first engine fitted with a steam trumpet or whistle. This trumpet was the suggestion of the manager, Mr. Bagster, to George Stephenson, who had it constructed by a local musical instrument maker.

The "Samson" and "Goliath," owing to their increased length and short wheel base, pitched seriously. To prevent this, Stephenson fitted a pair of trailing wheels behind the fire-box, as shown in red, and had the flanges removed from the middle pair of driving wheels. The success was so complete that he decided to discontinue building four-wheeled engines. The arrangement of the "Atlas" was derived from the improved "Samson" class by increasing the size of the added trailing wheels, and then coupling the three axles, but the boiler and cylinders were considerably larger, and the locomotive, which was the most powerful one of its time, weighed 17 tons. The company then purchased the "Liverpool," by Edward Bury, a four-wheeled engine weighing 10 tons; but although it worked well for many years, the succeeding engines were all heavier and closely resembled the "Atlas," although built by other makers. Further particulars of this interesting railway have been collected and published by Mr. Stretton.

141. Drawing of early locomotives built by Messrs. Edward Bury & Co., 1830–49. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1899. M.3072.

The firm of Messrs. Edward Bury and Co., of the Clarence Foundry, Liverpool, had existed for some years as a general engineering establishment, when, in 1829, they commenced the construction of their first locomotive. During the following twenty years 370 engines were ordered from the firm, but of these forty-one were built for them by other makers and five were never completed, so that the total number finished at the works, which were finally closed in 1850, was 324.

No. 1 engine on the firm's books was the "Dreadnought," completed in March, 1830. It had six coupled wheels, 48 in. diam., connected with an independent shaft upon which two outside inclined cylinders, 10 in. diam. by 24 in. stroke, acted; its tractive factor was therefore 50. The boiler was of the return flue type, with 200 sq. ft. of heating surface, and there was a tender at each end of the engine. This locomotive was from the first unsatisfactory, and was subsequently altered to the four-wheeled type, by the removal of the central axle; but, after having been

tried on several lines, it was dismantled within ten months of its completion.

No. 2 engine, the "Liverpool," commenced in January, 1831, embodied improvements suggested by the experience gained with No. 1 and by Mr. Kennedy, who had previously been engaged at Stephenson's works. It was a goods engine, with four coupled wheels, 54 in. diam., and a pair of inside cylinders 9 in. diam. by 18 in. stroke, so that its tractive factor was 27. The fire-box was of D section, with a domed top; the boiler had ninety-seven tubes and 360 sq. ft. of heating surface, and the framing was of the bar type. There was a single four-wheeled tender, and the whole arrangement embodied the distinctive features of the afterwards well-known Bury type of light engine. At its first trial on the Liverpool and Manchester Railway, in March, 1831, it was bought for the Petersburg Railroad of America, on which it worked successfully for several years.

No. 3 engine, the "Liver," built to the order of the Liverpool and Manchester Railway Co., was a four-wheeled passenger engine with a single pair of driving wheels, 60 in. diam., driven by inside cylinders 11 in. diam. by 16 in. stroke, so that its tractive factor was 32. Its weight in working order was 10 tons, and its heating surface 324 sq. ft.; the grate area was a little over 8 sq. ft. The engine ran 22,651 miles in the forty-three weeks that it worked in 1832, and 23,134 miles in the following year.

By the close of the year 1834 sixteen Bury locomotives had been constructed, of which nine were sent to America; the output subsequently increased, but about 1846 the firm, which had become Messrs. Bury, Curtis, and Kennedy, found that the light four-wheeled engine that they had persistently advocated was becoming unpopular, so a six-wheeled type was reluctantly introduced.

No. 190, built for the London and Birmingham Railway, in 1846, had four coupled wheels, 60 in. diam., and a pair of trailing wheels 42 in. diam. The cylinders were 15 in. diam. by 20 in. stroke, and the tractive factor was 75; the heating surface was 795 sq. ft.

No. 192 was also built in 1846 for the London and Birmingham Railway, and was a somewhat similar six-wheeled engine to No. 190, but had single drivers.

No. 220, built in 1846 for the Bristol and Birmingham Railway, had six wheels, 60 in. diam., all coupled and driven by a pair of cylinders 16 in. diam. by 24 in. stroke, giving a tractive factor of 102. The total heating surface was 1,014 sq. ft.

No. 280, built in 1847, followed a design that was accepted by several railway companies. It had four coupled wheels, 60 in. diam., with the fire-box placed between their axles, and a pair of leading wheels 48 in. diam.; the cylinders were 16 in. diam. by 22 in. stroke, and the tractive factor was 94. The heating surface was 1,011 sq. ft.

No. 301, built in 1848 for the London and North Western Railway, was a six-wheeled engine with a single pair of drivers, 78 in. diam., and a pair of cylinders 16 in. diam. by 22 in. stroke, giving a tractive factor of 72; in this design Bury abandoned his high-domed fire-box, and adopted what he termed his "low-domed" boiler.

No. 355 was the celebrated "Liverpool," built in 1848 for the London and North Western Railway, under Mr. T. R. Crampton's patent. It had eight wheels, but only a single pair of drivers, arranged behind the fire-box and driven by outside cylinders. The driving wheels were 96 in. diam., and the cylinders 18 in. diam. by 24 in. stroke, giving a tractive

factor of 81; the six other wheels were 48 in. diam. The grate area was 21·5 sq. ft., and the total heating surface 2,290 sq. ft., while the total wheel base was 18·5 ft. and the overall length of the engine 27 ft. The weight of the engine in working order was 35 tons, of which 12 tons were on the driving wheels; the weight of the tender was 21 tons. This engine conveyed express trains from London to Wolverton, and in one case kept time when hauling forty carriages, which was considered to exceed the combined power of three ordinary engines; when tested in 1849 with a light load, the engine attained a speed of 78 miles per hour (*see* also No. 155).

No. 359 was built in 1849 for the Great Northern Railway. It had four coupled wheels 69 in. diam., and a pair of leading wheels 51 in. diam., while the cylinders were 15 in. diam. by 22 in. stroke, giving a tractive factor of 72.

142. Drawing of "Pioneer" locomotive. Presented by C. and C. E. Stretton, Esqs., 1903. M.3299.

This represents an engine built by Messrs. Rothwell, Hick and Rothwell, at Bolton, in 1832, for the Bangor and Piscataguis Railway, U.S.A.

It was a four-wheeled passenger engine with inside cylinders 9 in. diam. by 18 in. stroke, and driving wheels 54 in. diam., thus having a tractive factor of 27. The valve chests were between the cylinders and the valves driven by loose eccentrics, hand levers being added for reversing. The boiler barrel was 32 in. diam., and contained forty-seven tubes 1·75 in. diam.; the fire-box was of the Bury type, D-shaped with a domed top surmounted by the safety-valve; the total heating surface was 182 sq. ft., and the grate area 6 sq. ft. The leading wheels were 36 in. diam. and the wheel base 5 ft.; the frames were of wood flitched with iron plates which also formed the axle-box guards.

143. Drawing of early locomotives. (Scale 1 : 24.) Built at the Vulcan Foundry, 1833–53. Prepared from particulars supplied by the Vulcan Foundry Co., 1896. M.2918.

The Vulcan Foundry at Newton-le-Willows, near Warrington, was established in 1832 by Charles Tayleur, of Liverpool, and George Stephenson. At the time Lancashire was a centre of railway enterprise, so that the new works were soon fully engaged on general constructional iron work as well as in locomotive building. Their first locomotive was named "Tayleur," and the second "Stephenson"; both were completed in 1833, and in 1840 the works built their 100th engine. In 1847 the name of the firm was changed from Charles Tayleur and Co. to the Vulcan Foundry Co.

The sheet shows ten of the early locomotives constructed at these works; the examples have been so selected as to indicate the variety in the types then built.

No. 4, built 1833, for the Camden and Woodbury Railroad, U.S.A., was a bogie engine with 9 in. by 14 in. inside cylinders and single drivers 54 in. diam., with the cranked axle behind the fire-box, the tractive factor being 21.

No. 8, built 1834, for the Liverpool and Manchester Railway, was a four-wheeled goods engine, with 11 in. by 20 in. inside cylinders and wheels 60 in. diam., the tractive factor being 40·3.

No. 20, built 1835, for the South Carolina Railroad, U.S.A., was a bogie engine, with 10 in. by 16 in. outside cylinders and single drivers 54 in. diam., the tractive factor being 30; the bogie wheels were of two sizes.

No. 25, built 1836, was No. 1 engine of the London and Greenwich Railway; it was a four-wheeled locomotive, with inside cylinders 10 in. by 16 in. and single drivers 60 in. diam., the tractive factor being 21.

No. 35, built 1836, for Mr. Hargreaves, of Bolton, was a six-wheeled engine with four coupled drivers 68 in. diam. and 13 in. by 18 in. inside cylinders, the tractive factor being 45. It is shown on stone sleepers and a parallel rail of the period.

No. 52, built 1837, for the Great Western Railway (7 ft. gauge), is a six-wheeled engine with single drivers 96 in. diam., and 14 in. by 16 in. inside cylinders, the tractive factor being 33.

No. 61, built 1838, was a light engine used by a contractor on the London and Birmingham line. It had 12 in. by 16 in. inside cylinders and 54 in. single drivers, the tractive factor being 43.

No. 231, built 1845, for the line between Bristol and Birmingham, was a six-wheeled engine with single drivers behind, 72 in. diam., and 15 in. by 24 in. outside cylinders, arranged between four wheels of equal size; the tractive factor was 75.

No. 316, built 1848, for the Shrewsbury and Chester Railway, was a four-wheeled inside cylinder engine with a wheel base of 11·5 ft. The wheels, 63 in. diam., were coupled to an intermediate axle, which was driven by 16 in. by 24 in. inside cylinders, giving a tractive factor of 97·5.

No. 346, built 1853, for the Shrewsbury and Hereford Railway, was a six-wheeled engine, with single drivers 66 in. diam., driven by 15 in. by 20 in. inside cylinders, but with the valve chests and motions outside, the frames; the tractive factor was 68.

A lithograph on the wall shows the firm's practice in 1838, while on the Leicester and Swannington sheet (*see* No. 140) is shown another engine by the Vulcan Co.

144. Six sheets of diagrams of locomotives. (Scale 1 : 96.) Presented by Theodore West, Esq., 1886. M.2769.

The originals were prepared to illustrate a paper read by Mr. West before the Cleveland Institution of Engineers in 1886, on the development of the locomotive in this country and America. The outlines are to scale, and the leading dimensions and particulars of the engines are given on the sheets.

145. Photograph of "Hibernia" locomotive. Received 1865. M.2767.

This was one of the three engines built in 1834 by Messrs. Sharp, Roberts, and Co., of Manchester, for the Dublin and Kingstown Railway. They were of a novel type proposed by Richard Roberts, the cylinders being placed vertically over the centre line of the leading wheels, and working the driving wheels by connecting-rods and equal-armed bell cranks. The cylinders were 11 in. diam. by 16 in. stroke, and the driving wheels 60 in., giving a tractive factor of 45; the leading wheels were 36 in. diam. There were no eccentrics to actuate the

valves, short arms on the bell-cranks being used instead to move rocking shafts near the foot-plate. The valves were tubular without lap or lead, and the pistons were without rings, but had white-metal bands exactly fitting the cylinders.

The engines proved unsteady in running, so that, with the exception of the "Experiment," for the Liverpool and Manchester Railway, no others were built.

146. Diagram model of balanced locomotive with expansion gear (working). (Scale 1 : 3.) Contributed by R. Bodmer, Esq. M.14.

This shows a method of completely balancing the reciprocating parts of a locomotive, patented by Mr. J. G. Bodmer in 1834. The cylinder has two pistons, one having a tubular rod within which the other rod slides, and each pair of pistons is connected with cranks at 180 deg., so that the pistons continually move in opposite directions, thus balancing their inertia stresses. The construction was applied practically with some success.

The valve shown is of the piston type, and has adjustable lap (*see* No. 196).

147. Model of passenger locomotive (working). 1837. (Scale 1 : 12.) Received 1896. M.2939.

This model was made by Mr. J. Dawson, District Superintendent at Southampton, of the London and Southampton, now the London and South Western Railway. It represents an engine of the standard passenger type of the period. It had six wheels, a single driving axle, inside cylinders and outside frames.

The cylinders were 12 in. diam., by 18 in. stroke, and the driving wheels were 60 in. diam., so that the tractive factor was 43. The leading and trailing wheels were 42 in. diam., and the wheel base was 11 ft. The smoke-box completely enclosed and supported the cylinders, but the valves were placed above them and not between, as generally arranged somewhat later. The crosshead guides were of the four-bar type, and above them were arranged rocking shafts for driving the slide valves.

As this model was made before the introduction of the now almost universal link motion, its valve gear is of particular interest. The valve of each cylinder was provided with two eccentrics, one for forward running and the other for backward; the ends of the eccentric rods finished in notches or gabs and were supported by links from a horizontal reversing shaft. Each pair of gabs embraced a pin connected with one of the slide valve rods. By a lever on the right-hand side of the platform the reversing shaft could be turned so as to throw one set of gabs off the valve pins and the other set on, or leave them in the intermediate position when the valve rods were free for independent movement by the hand levers, which were on the left side of the platform, one lever being provided for each cylinder. This gear entailed the manipulation of three levers in reversing and gave no means of altering the cut off, but it contained the four eccentrics of the present locomotive link motion.

The boiler had a barrel 42 in. diam., and 8 ft. long, with a fire-box of

circular section having a domed crown; the inner fire-box was flattened to form the tube plate. A spring loaded safety valve was mounted on a dome over the fire-box and another on the barrel. Two long stroke feed pumps were provided, driven directly from the crossheads.

The frames shown are of solid bars, but it is probable that they were intended to represent the early timber frames which were flitched with iron plates on both sides. The boiler was carried on wrought iron brackets resting on the frames. There was no shelter for the driver, the only protection on these early locomotives being a handrail as shown.

148. Drawing of early locomotives of the Great Western Railway, 1837–55. (Scale 1 : 24.) Prepared chiefly from particulars and tracings furnished by C. E. Stretton, Esq., 1898. M.3017.

The prospectus of the Great Western Railway Co. was issued in 1833, the Act authorising construction was passed in 1835, and the broad gauge of 7 ft., proposed by Brunel in 1835, was sanctioned by Parliament in 1837. The first section of the line, from Paddington to Maidenhead, a distance of 22·5 miles, was opened in 1838, and the line to Bristol in 1841; the extensions to Cornwall, South Wales, and Cheshire were carried out subsequently. The rails used were of the bridge section, weighing 44 lbs. per yard, and were supported on longitudinal sleepers resting on short piles and tied together by transoms. The piles were soon abandoned, but the longitudinal system was retained, the extra width of the broad gauge probably rendering it more economical than the use of transverse sleepers. In 1845 the railway had 274 miles of line laid with the broad gauge exclusively; in 1854 the mixed gauge, obtained by the use of three rails, which had been introduced in 1847, was extensively adopted; but by 1867 the broad gauge track had increased to 1,456 miles. In 1869 was commenced the conversion of some of the mixed gauge track into narrow gauge, and at the same time the manufacture of unconvertible broad gauge stock was restricted; in 1892 the broad gauge rolling stock was entirely withdrawn, and the system has since been worked exclusively on the standard gauge of 4 ft. 8·5 in. An adjacent photograph shows the last broad gauge mail train leaving Paddington station, May 20th, 1892.

The first engine of the Great Western Railway was the "North Star," built in 1837 by Messrs. R. Stephenson and Co. Although not designed for this line, it remained in use till 1870, and ran more than 400,000 miles. It had a pair of inside cylinders, 16 in. diam. by 18 in. stroke, and single driving wheels 7 ft. diam., giving a tractive factor of 55. The heating surface was 850 sq. ft., and the grate area 11·76 sq. ft. The link motion shown was added some years after the engine was built. This engine was the first of twelve forming the "Star" class, all built for this line by Messrs. R. Stephenson and Co. in 1837–41.

"Vulcan," the second engine of the line, was built in 1837 by the Vulcan Foundry Co., being No. 52 in their books. It was a six-wheeled engine with single driving wheels 96 in. diam., and inside cylinders 14 in. diam. by 16 in. stroke; the tractive factor was 32·6.

"Lion," the seventh engine of the railway, was built by Messrs. Sharp, Roberts and Co., in 1838. It was a six-wheeled engine, with inside cylinders 14 in. diam. by 18 in. stroke, and a pair of single 6 ft. driving wheels. The tractive factor was 49.

"Ajax," the fifteenth engine on the line, was built in 1838 by Messrs. Mather, Dixon and Co., of Liverpool. It was a six-wheeled engine with

inside cylinders, and outside frames and axle bearings; the cylinders were 14 in. diam. by 18 in. stroke, and drove a single pair of driving wheels 8 ft. in diameter, giving a tractive factor of 36·7. These wheels were without spokes, two discs of boiler plate held together by screwed stays being substituted in each; the discs, which were ·56 in. thick, were 7 in. apart at the boss and 3·5 in. at the rim.

"Fire-fly" was built in 1840 by Messrs. Jones, Turner, and Evans, to designs by Sir D. Gooch. It had a pair of inside cylinders 15 in. diam. by 18 in. stroke and single drivers 7 ft. diameter; the tractive factor was 48, and the engine in working order weighed 24·2 tons. Altogether sixty engines to this design were constructed by various makers.

"Iron Duke" was built at the Swindon Works in 1847, to designs by Sir D. Gooch; the cylinders, 18 in. diam. by 24 in. stroke, worked single drivers 96 in. diam., thus giving a tractive factor of 81. The grate surface was 21 sq. ft., and the total heating surface 1,952 sq. ft. The "Iron Duke" is shown with its tender, as both remained for many years the standards for the Great Western line, until the abolition of the 7 ft. gauge was definitely decided upon. The engine had four small wheels in front, with the axle-boxes on each side connected by a single plate spring, which acted also as an equalising lever, an arrangement that was extensively adopted for many years, but was ultimately replaced by the bogie.

"Lalla Rookh" was built in 1855 by Messrs. R. Stephenson and Co., to designs by Sir D. Gooch; it had 17 in. cylinders by 24 in. stroke, and coupled drivers 7 ft. in diameter, giving a tractive factor of 82·5. This adaptation of the "Iron Duke" design to an engine with coupled drivers was followed in ten engines, but was not afterwards repeated.

149. Model of coupling wheels for locomotives. (Scale 1 : 8.) Contributed by W. B. Adams, Esq., 1869. M.1121.

This method of connecting the wheels of a locomotive, so that the adhesion due to the total weight of the engine shall be available for tractive purposes, was provisionally patented by Mr. Adams in 1855; the arrangement had, however, been patented in 1837 by Mr. J. Melling, so Mr. Adams did not proceed with it. In recent years the device has been tried on a practical scale in America; it enables wheels of different diameters to be coupled, and also gives a connection that may be temporarily made when required, even while running.

The model represents a radiating axle frame (*see* No. 769), with eight travelling wheels, of which the front four are frictionally coupled by an elevated pair of wheels pressing upon them, while the hind four wheels are similarly connected by another pair. The upper axles may be independently driven, but as here represented the central pairs of travelling wheels are to be connected by coupling-rods, one pair only being directly driven. Arrangements are made for throwing any required proportion of the weight of the engine upon the elevated axles. In Melling's specification steam-moved levers were introduced for this purpose.

150. Photographs of early American locomotives. Presented by C. E. and C. Stretton, Esqs., 1900. M.3103.

These were taken from the relics and models of America's first locomotives, dating between 1831 and 1844, as exhibited at Chicago in 1893. Each has a short description beneath it.

151. Model of early Austrian locomotive (working). (Scale 1 : 6.) Made by Philipp Wolf. Received 1902. M.3212.

This model, which was made in 1843, represents a type of locomotive introduced in 1837 by William Norris of Philadelphia, for working on lines having steep inclines and sharp curves; such engines were largely used on the Austrian railways at their commencement in 1838, and many of the class were subsequently built at Vienna. Similar locomotives were sent by Norris to England in 1840, and some of them were used for working the Lickey incline on the Birmingham and Gloucester Railway.

The engine represented had inclined outside cylinders, and a single driving axle in front of the fire-box, while the forward end of the engine was carried by a four-wheeled swivelling bogie, so that great flexibility was secured. The cylinders were 10·5 in. diam. by 21 in. stroke and the driving wheels 46·5 in. diam. so that the tractive factor was 50; the bogie wheels were 30 in. diam., with their centres 2·875 ft. apart, while the total wheel base of the engine was 9·875 ft. on a gauge of 5 ft. Each cylinder was provided with two square guide bars, and the crossheads working on them had adjustable slide blocks.

The valve chests were arranged above the cylinders and the valve rods were driven, through a rocking shaft, by four eccentrics on the driving axle. There was a forward and a backward eccentric to each cylinder, and each eccentric rod ended in a notch provided with a spreading jaw or "gab"; the gab ends of each pair of rods faced each other and were suspended by links from a reversing shaft actuated by a lever on the foot-plate, so that either the forward or the backward eccentrics could be used for actuating the valves. As there was no intermediate position, this valve gear did not permit of the grade of expansion being altered, so that the speed was regulated entirely by throttling.

The boiler was tubulous, with a barrel 8·25 ft. long by 38 in. diam. and it had a domed fire-box of the Bury type, while the grate was D-shaped in plan; the heating surface was probably 400 sq. ft. and the grate area 6 sq. ft. The dome was surmounted by a spring-loaded lever safety valve, while over the middle of the boiler barrel was a locked-up safety valve directly loaded by plate springs. The regulating valve was of the sliding type, manipulated by a vertical lever above the fire-door; the model shows also a glass water-gauge and a steam whistle. The feed water was introduced by two long-stroke feed pumps, directly driven from the crossheads, and special arrangements were made to render the pump and check valves readily accessible; the suction pipe of each pump was fitted with a cock controlled from the foot-plate.

The frame was of the bar construction, and the boiler was supported from it by brackets; the framing rested on the bogie carriage at each side, while a central swivel pin connected it with the bogie. The horns were forged with the framing, which was strengthened by inclined struts passing under the horns and riveted to the framing at each end; the driving axle and those of the bogie were provided with separately adjustable plate springs. The foot-plate was carried by an extension of the framing and was fitted with a hand rail, but no protection against the weather was provided; the length of the engine was 20 ft. and its weight in working condition about 10 tons.

The tender was built on double frames with the springs and axle-boxes between them; the water tank was of a horse-shoe shape, and

the central space was the fuel receptacle. The tender was carried on four wheels, 30 in. diam., and had a wheel base of 4·875 ft.; it was fitted with brake blocks between one pair of wheels and the brakes were applied by a screw actuating a vertical wedge. The engine and tender were closely connected by a pin coupling, and were provided with two padded buffers at the ends; the overall length of engine and tender was 32 ft. and the total weight about 14 tons.

152. Drawings of experimental locomotives on the Great Western Railway. (Scale 1 : 24.) Presented by C. E. Stretton, Esq., 1891. M.2382.

These blue prints represent the engines "Hurricane" and "Thunderer," designed by Mr. T. E. Harrison, and constructed by Messrs. R. and W. Hawthorn, of Newcastle, in 1838. In both engines the plan, patented by Mr. Harrison in 1836, of separating the boiler from the engines was followed. The object of the arrangement was to enable a fresh boiler carriage to be attached to the engine carriage, while the former was under repair, and *vice versâ*.

The "Hurricane" had two cylinders 16 in. diam., 20 in. stroke, working direct on to single driving wheels 10 ft. diam. The "Thunderer" had two cylinders 16 in. diam., and 20 in. stroke, working on to a crank-shaft which, by spur gearing in the ratio of 3 : 1, was connected with four coupled driving wheels 6 ft. diam.; the gearing made the equivalent diameter 18 ft. Both engines were failures, probably largely owing to the weight on the driving wheels being so small.

153. Photographs of London and North Western locomotives. Lent by A. M. H. Soloman, Esq., 1899. M.3068.

These show typical engines used on this line between 1839–99. Each photograph has a short description beneath it.

154. Model of "Bury" passenger locomotive (working). (Scale 1 : 12.) Made by W. Eaves. Plate V., No. 6. Received 1905. M.3399.

This model, which was made in 1846, represents a type of locomotive ntroduced by Edward Bury and Co. in 1832 (*see* No. 141), but the engine shown was built about 1840, probably for the Midland Counties Railway. The engines of Bury's design were of very simple form, having only four wheels and inside cylinders directly attached to inside bar framing, so that no driving stresses were imposed on the boiler. The crank-shaft had two bearings only instead of the five or six usual at the period. The feature of the boiler was the D-shaped fire-box with its high domed crown. These four-wheeled engines were found to oscillate considerably at high speeds, but this defect was remedied by introducing a pair of trailing wheels as shown in the model. Locomotives of this type were employed on many lines and exclusively used on the London and Birmingham Railway from 1837 to 1846.

A tender was made from drawings prepared in the Museum, and was added to the model in 1906 to complete the exhibit; it represents the form in general use from about 1833–1840.

The engine represented had horizontal cylinders 12 in. diam. by 18

in. stroke and single driving wheels 66 in. diam. placed in front of the fire-box; the tractive factor was 39·3. The leading wheels were 48 in. diam. and the trailing wheels 36 in. diam. The cylinders were bolted to a pair of cross-bars secured to the frames at their ends, and were each provided with four guide bars. The valve chests were placed above the cylinders, in the smoke-box, and the valve rods were driven through rocking shafts by four fixed eccentrics on the driving axle. There was a forward and backward eccentric to each cylinder and the eccentric rods had notches or gabs at their ends, provided with long spreading jaws opening downward, which engaged with pins on the valve levers. One rod of each pair was suspended from a lever on a reversing shaft which was cranked backward in the middle, while the other two were hung from a lever pivoted at one end and having a slot engaging with the crank. The reversing shaft was actuated by a lever on the foot-plate so that one pair of forks was lowered into gear while the other pair was lifted out; this reversing gear did not permit of variable expansion. The addition of forks to the gabs enabled the eccentric rods to be put in gear at any position of the valves, and thus dispensed with the levers necessary in the earlier gears for working the valves by hand.

The boiler barrel was 37·5 in. diam. inside and 8·21 ft. long, the D-shaped fire-box being 47·5 in. wide and 39·5 in. long; the internal fire-box was of iron. There were eighty-six tubes, 1·875 in. external diam., having a heating surface of 362 sq. ft.; the fire-box heating surface was 38 sq. ft., and the grate area 7·6 sq. ft. A small dome on the top of the fire-box accommodated the steam pipe and was surmounted by a spring-loaded lever safety valve, while on the barrel was a lock-up safety valve directly loaded by a helical spring. The regulator was of the rotary type manipulated by a lever over the fire door; a fitting was attached on one side of the fire-box carrying a water gauge, cocks, and a whistle. The feed water was introduced by two long stroke feed pumps driven directly from the crossheads.

The frame was formed of single flat bars having the axle box guides forged or bolted on, and was trussed with round bars; the boiler was supported from it by brackets. The draw-bar was attached to a stirrup secured to the frames and embracing the fire-box; the axles were provided with separate plate springs placed above them. The wheels were built up with cast iron naves and wrought iron spokes, rims, and tires. The spokes had T heads riveted to the rims, while their inner ends were coned and cottered into sockets in the naves. The foot plate was carried on the rear end of the frame and was fitted with a hand rail. The length of the engine was 17·75 ft. and its total wheel base 10·42 ft., but only 5·5 ft. without the trailing axle; its weight in working order was about 11 tons, of which 6 tons were carried by the driving wheels.

The tender, which was carried on four wheels 36 in. diam., had a wheel base of 4·58 ft. The frame-work was built up of wooden beams, the side frames being double with the wheels between them and covered on the outside with ornamental iron plates. The water tank was of horse-shoe shape and rested on the tops of the frames, being held by large angle irons at the corners; the coal space between the frames was lined with sheet iron. The bearings were outside the wheels with the plate springs above them. Wooden brake blocks were fitted between the wheels on one side and these were applied by a screw actuating a vertical wedge. The buffers were padded and mounted

on sliding stems which engaged with the ends of a transverse spring. The engine and tender were closely connected by a link and pin coupling having swivel joints. The tank held 640 galls. of water and about 10 cwts. of coal were carried.

The weight of the engine and tender in working order was about 17·5 tons and the overall length 30·1 ft.

155. Model of Crampton's locomotive (working). (Scale 3 : 20.) Lent by T. R. Crampton, Esq., 1876. Plate V., No. 7. M.1787.

This represents an express passenger engine of the type designed and patented by Mr. Crampton in 1842–47, and built by Messrs. Derosne and Cail, Paris, for the Northern Railway of France, in 1849. The general arrangement shown was adopted in order to keep the centre of gravity low, and at the same time to use large single driving wheels which were carried on an axle behind the fire-box. Locomotives of this design worked the French express services from 1849 until about 1876, and Crampton engines of the Folkestone class (*see* No. 136) ran for a time on the South Eastern and Great Northern Railways. Four-coupled engines with the same arrangement of mechanism were also employed on the London, Chatham, and Dover line.

The engine was carried on six wheels and had outside cylinders 15·75 in. diam. by 22 in. stroke; the driving wheels were 82·6 in. diam., and the tractive factor 66. The piston rods were extended through the front cylinder covers and formed plungers for long stroke feed-pumps. The valve chests were on the tops of the cylinders, inclined outward, and the valves were driven by eccentrics, mounted on a return crank, through the usual shifting link motion, so that the whole of the mechanism was exposed to view and easily accessible. The frames were double and tied together by transverse stays, and the cylinders were bolted between the plates of each frame. The two leading axles had outside bearings and the driving axle inside bearings only, the load being suspended by laminated springs placed above them.

The boiler barrel was 4 ft. diam., and 11·92 ft. long between the tube plates, its centre being only 4·72 ft. above the rails. It contained 173 tubes of 2 in. external diam. and four tubes of 1·75 in. diam., these having a heating surface of 1,070 sq. ft.; the fire-box had a heating surface of 79 sq. ft. and a grate area of 15·4 sq. ft. The regulator was placed in a chamber on the barrel and external steam pipes led to the cylinders. Two spring balance safety valves were provided. The smoke-box was formed as an extension of the boiler barrel, and the two exhaust pipes were led to a blast nozzle having an orifice whose area was adjustable by means of two hinged flaps.

The rigid wheel base of the engine was 15·94 ft.; the front wheels were 51 in. diam. and the middle ones 48 in. diam. The weight of the engine in working order was 27 tons, the leading and driving wheels carrying 11·5 tons each and the middle ones only 4 tons, this distribution being adopted to ensure steady running. The tender was carried on four wheels 42·2 in. diam. with a wheel base of 8·2 ft.; it had hand brakes on the wheels and a horse-shoe shaped water tank. The overall length of engine and tender was 45 ft.

156. Model of passenger locomotive and tender (working). (Scale 1 : 9.) Received 1906. M.3448.

This represents the type of inside cylinder passenger engine which was in general use for many years subsequent to its introduction by Mr. John Gray, in 1846; its extensive use was, however, largely due to the success of the engine "Jenny Lind," built by Messrs. E. B. Wilson and Co., of Leeds, in 1847. These engines had six wheels, double frames, and a single driving axle having inside bearings only, while the leading and trailing axles had outside bearings.

The model shows an engine of this type built about 1860. It had double slab frames running from end to end and braced by the cylinders and transverse frames. The cylinders were placed horizontally under the smoke box with the valve chests between them. The valves were driven by Howe's link motion. The intermediate valve rod was suspended by a link, and reversing was effected by a lever and quadrant, through a weighted countershaft below. Each crosshead had four guide bars whose rear ends were supported by a transverse plate which also supported the boiler barrel and the reversing shaft. The boiler was provided with a steam dome on the barrel surmounted by a spring balance safety valve, and the usual fittings on the back plate of the fire-box. The feed water was supplied by two long stroke feed pumps bolted to the frames and driven directly by the crossheads. A simple weather plate was provided for the protection of the driver and fireman.

The tender was carried on six wheels and was fitted with brakes which were applied by a hand wheel and screw.

157. Model of Indian locomotive and tender. (Scale 1 : 4.) Contributed by Lieut.-Col. J. P. Kennedy, 1863. M.909.

This engine was built by Messrs. E. B. Wilson and Co., in 1856, at the Railway Foundry, Leeds, for the Bombay, Baroda, and Central India Railway, then in process of construction.

It has outside inclined cylinders 14 in. diam. by 24 in. stroke, and four coupled drivers 60 in. diam., giving a tractive factor of 78·4. The leading wheels are 40 in. diam. The engine weighs about 22·4 tons; the gauge is 5·5 ft.

158. Model of Ramsbottom's water scoop for supplying locomotives. (Scale 1 : 6.) Lent by J. Ramsbottom, Esq., 1893. M.2502.

This represents a locomotive tender fitted with Ramsbottom's arrangement for picking up the feed-water while a train is running, an arrangement introduced in the year 1860, on the London and North Western Railway.

A cast-iron trough, 440 yds. long, 18 in. wide, and 6 in. deep, cast in 6 ft. lengths and jointed with india-rubber cord, is placed between the rails and secured to the sleepers. Between the ends of this trough the rails dip about 6 in., so that the water-lifting arrangement clears the ends of the trough but dips into it for the rest of its length.

From the bottom of the tender a large rectangular pipe passes to within 18 in. of the trough, and is provided with a continuation finishing

in the form of a scoop 10 in. wide and 2 in. deep, which is carried on a horizontal axis, round which it can be rotated so as to be well clear of the road when not in use. The model shows the delivery pipe entering the floor of the tender and being there closed by a flap valve, but in practice the pipe is usually carried to the top of the tender and then turned downward, so dispensing with the use of a valve. The extra lift thus entailed is not of importance, as at a speed of 22 miles per hour the scoop picks up its full quantity of 400 gallons in passing over the trough.

159. Model of an Egyptian locomotive (working). (Scale 1 : 8.) Lent by T. Jeffrey, Esq., 1870. M.1828.

This represents a tank engine built in 1862 at Alexandria by Jeffrey Bey, for working the train service between Alexandria and Suez.

It is a four-wheeled engine with a single pair of drivers 5 ft. diam.; the cylinders are of the outside type, 13 in. diam., and 20 in. stroke, giving a tractive factor of 56. The valve gear is of the usual shifting link form; the valve boxes are inside, and two long-stroke feed pumps are arranged beneath the cylinders, the plungers being directly connected with the crossheads. The tank is arranged beneath the boiler, and the weigh-shaft for the link motion is carried through a horizontal tube in the tank. The smoke-box is produced downward and formed into a second tank, which is an extension of the main one. Two coal bunkers are arranged, one on each side of the fire-box, whereby the overall length of the locomotive is reduced. The blast pipe terminates in a series of nozzles superposed. The gauge fittings are all fixed to a water column attached to the boiler. The various accessories of a locomotive are also shown, including a traversing screw-jack, the stoking and firing irons, fire-bars, lanterns, etc. The engine is provided with a hand-brake, which acts on the driving wheels, and a light cab is fitted over the foot plate to afford shelter from the intense heat of the sun.

160. Model of a six-coupled goods engine (working). Received 1892. M.2447.

This represents an inside cylinder engine with six coupled wheels 4 ft. diam. The cylinders incline slightly downward, so that while high enough to clear the leading wheels, they act directly on the central driving axle, which has two cranks at right angles and also the four eccentrics of the valve motion, the arrangement of which is commonly known as Stephenson's link. The cylinder slide valves are above the cylinders, and receive their motion through a weigh-shaft. The feed is supplied by a vertical fly-wheel donkey pump at the side of the fire-box, this model having been made before the general use of the injector. The method in which three axles are coupled so that the adhesion of all six wheels is utilised for traction, is also clearly shown.

The tender shows a very useful type of construction, and is fitted with six wheels and provided with a powerful hand-brake.

161. Model of American locomotive (working). (Scale 1 : 8.) Received 1880. M.1495.

This represents a passenger locomotive, built about 1875, for the Erie Railroad, and is of the then typical American construction, with outside cylinders, four coupled driving wheels, and a leading bogie.

The framing is of the bar type almost universally adopted in America, where its flexibility is considered to reduce the strains due to irregularities in the permanent way. The valve chests are above the cylinders, the valves deriving their motion from a weigh-shaft driven by Howe's link motion from inside eccentrics. The boiler has the waggon-topped external fire-box—a distinctive feature of American practice. The boiler is fed by an injector and also a feed pump driven from one crosshead. The tender is carried on two bogies, a large enclosed cab is provided for the driver and stoker, while, owing to the unprotected state of the railroad and the frequent occurrence of level crossings, a "cow-catcher" is fixed to the buffer beam; a large bell is carried on the boiler and a head lamp on the smoke-box.

Although a working model, some of the details are not to scale, but the engine would have cylinders 15 in. diam. by 20 in. stroke, and driving wheels 56 in. diam., giving a tractive factor of 80.

162. Model of Fairlie locomotive (working). (Scale 1 : 12.) Received 1892. M.2450.

This embodies the leading features of Mr. R. F. Fairlie's patented arrangement of 1864, by which a large amount of tractive power is obtainable from a locomotive that could work on a light rail and pass round sharp curves.

The boiler is mounted on the centre of two frames, each forming a distinct engine complete in itself, but both receiving steam from the common boiler which is of considerable length, and has two fire-boxes near the middle with a chimney and smoke-box at each end. The engine-driver stands at one side of the fire-box and the fireman at the other, protection being afforded by a central cab. The frames or bogie trucks have each two cylinders and six coupled wheels, each bogie carrying one half of the weight of the boiler by a central pivot. The steam is conducted from the boiler to the cylinders by two telescopic swivel pipes and a similar arrangement conveys the exhaust to the chimneys. The valve gear is of the Walschaërts' type, in which the leading feature is that motion from a single eccentric is combined with the motion of the crosshead. The valve gears of the two engines are coupled up, so that they are simultaneously controlled by a single reversing lever.

There are two coal bunkers and two water tanks on the side of the boiler and two additional water tanks beneath the platform. The feed is given by a direct-acting steam pump above the boiler, and two large sand boxes are carried behind the chimneys, the engine being fitted for running in either direction, so avoiding the use of turn-tables.

An engine of this type built by Messrs. Neilson and Co. for service in Mexico closely resembles this; the cylinders were 16 in. diam. by 22 in. stroke, with driving wheels 45 in. diam., giving a total tractive factor of 250. The heating surface was 166 + 1,647 sq. ft., the total wheel base 30·25 ft., and the rigid base in each engine only 8·25 ft. The total weight in working order was 92·2 tons.

The peculiar bridge on which the model is shown was made to demonstrate the flexibility of the wheel base and also to facilitate inspection of the model.

163. Perspective drawing of Great Northern Railway express engine, 1870–90. Received 1898. M.3035.

Previously to 1870, Mr. Patrick Stirling had employed on the express traffic of the Great Northern Railway a class of engine with a single pair of driving wheels 7 ft. diam., and cylinders 17 in. diam. by 24 in. stroke, giving a tractive factor of 82·5.

In 1870 he introduced the more powerful engines of the same type here represented, with driving wheels 8 ft. in diam., which for over twenty years worked most successfully and remained almost unaltered. These engines have a pair of outside cylinders 18 in. diam. by 28 in. stroke, with single driving wheels 97·5 in. diam., giving a tractive factor of 93. The large driving wheels caused the cylinders to be placed outside; but in economy and steadiness there is little difference to be detected between these engines and some similar ones with the cylinders inside.

The boiler possesses 17·75 sq. ft. of grate area and 1,045 sq. ft. of heating surface, 936 sq. ft. of which are given by 174 tubes 1·75 in. diam. The working pressure was originally 140 lbs., but is now 170 lbs. per sq. in.

The total weight in running order is 85·4 tons, distributed as follows: on bogie, 17·55 tons; on driving wheels, 17 tons; on trailing wheels, 10·6 tons; tender with 3,500 galls. water and 5 tons coal, 40·25 tons.

164. Model of express passenger locomotive. Great Northern Railway (working). (Scale 1 : 8.) Made by Messrs. Baines Bros. Received 1905. M.3419.

This represents the celebrated class of locomotives, with single driving wheels 8 ft. diam., designed and introduced by Mr. Patrick Stirling in 1870. These engines successfully worked the express traffic for about thirty years, but they have now been superseded on the heavier trains by more powerful coupled engines.

The engine represented, which differs but slightly from the earlier ones, was built at the Doncaster Works in 1887. It has a pair of horizontal outside cylinders, 18 in. diam. by 28 in. stroke, with driving wheels 97·5 in. diam., giving a tractive factor of 93. The steam chests pass through the frames and the valves are driven by the usual shifting link motion, controlled from the foot plate by a lever and quadrant.

The boiler barrel is 48 in. mean internal diam. by 11·42 ft. long and contains 174 copper tubes of 1·75 in. diam., having a heating surface of 936 sq. ft. The fire-box has a heating surface of 109 sq. ft. and a grate area of 17·75 sq. ft. The steam pressure is limited to 170 lbs. per sq. in. by Ramsbottom safety valves and the steam is collected by a perforated pipe running along the upper part of the barrel, the regulator being placed in the smoke box. The fire-box crown is tied to the outer shell by screwed stays and the end plates to the barrel by diagonal stays. The feed water is supplied from the tender by two injectors and enters the back plate, being led to the centre of the barrel by an internal pipe.

The front end of the engine is carried on a bogie, whose pivot is placed behind the centre, there being no transverse motion; its wheels are 47·5 in. diam. and its wheel base 6·5 ft. The rear end is supported by a trailing axle with wheels 55·5 in. diam. and the driving axle is

fitted with helical springs. A vacuum cylinder beneath the foot plate applies the brake blocks to the driving and trailing wheels.

The engine has a wheel base of 22·92 ft. and an overall length of 29·75 ft. Its weight in working order is 45·15 tons, of which 17 tons rest on the driving wheels. The tender in use in 1887 had six wheels 49·5 in. diam. and carried 2,900 galls. of water and 5 tons of coal, its weight being 33·4 tons.

165. Model of goods locomotive of the North London Railway. (Scale 1 : 24.) Lent by E. A. Forward, Esq., 1902. M.3213.

This represents a class of six-coupled tank locomotive designed by Mr. J. C. Park in 1879 and subsequently constructed at the Bow Works as the standard goods engine of this suburban line.

The engine has horizontal outside cylinders 17 in. diam. by 24 in. stroke, and steel-tired cast iron wheels 52 in. diam., so that the tractive factor is 133. Each crosshead works on a single guide bar arranged above it, and the driving crank-pin, which carries two coupling-rod ends as well as the connecting-rod end, side by side, is 9·5 in. long. The valve gear is of the usual moving link type, but the valve-rods are bent to clear the leading axle, and are suspended from the frame by links which replace the more usual guides.

The boiler shell is of steel and the barrel, which is 49 in. diam. and 9·7 ft. long, contains 192 steel tubes 1·75 in. external diam. and ·095 in. thick. The fire-box is of copper and has a grate area of 16·3 sq. ft. and 81 sq. ft. of heating surface, while the tube surface is 876 sq. ft. The working pressure is 160 lbs. per sq. in. and is limited by a Ramsbottom's double safety valve; a steam dome is provided, and within it the regulating valve is arranged.

The water is carried in a pair of side tanks, having a capacity of 956 galls., and the boiler is fed by two Gresham injectors. The bunker, which holds 1·25 tons of coal, is at the rear of the footplate and enclosed by the cab. A screw brake is provided which applies wooden blocks to the driving and trailing wheels only; sand boxes are fitted to the leading and trailing wheels.

The weight of the engine, complete in working order, is 44 tons, and this is equally distributed over the three axles. The wheel base is 11·33 ft. and the engine easily passes round curves of 5 chains radius; the overall length is 27·8 ft.

Photographs of the standard goods and passenger engines of this line are shown near.

166. Lithographed drawings of locomotives fitted with Joy's valve gear. Lent by Messrs. David Joy and Son, 1901. M.3204.

One drawing shows a four-coupled bogie engine for the Midland Railway, built at Derby in 1885. It has inside cylinders 19 in. diam. by 26 in. stroke, and driving wheels 84 in. diam. giving a tractive factor of 112. The boiler has a heating surface of 1,122 sq. ft. and a grate area of 17·5 sq. ft. The weight in working order is 42·8 tons.

The other drawing shows a four-coupled tank engine with a radial axle at each end, built at the Stratford Works of the Great Eastern Railway in 1885. It has inside cylinders 18 in. diam. by 24 in. stroke, and driving wheels 64 in. diam. giving a tractive factor of 121. The

boiler has a heating surface of 1,054 sq. ft. and a grate area of 15·43 sq. ft. The weight in working order is 51·9 tons.

167. Model of Adams' locomotive blast pipe. (Scale 1 : 4.) Lent by W. Adams, Esq., 1890. M.2309.

By this arrangement the exhaust steam is discharged as a hollow cylindrical jet, thereby greatly increasing the amount of surface presented to the gases in the smoke-box, so that a greater exhaustive effect is produced. The gases carried into the chimney by the external surface of the jet are gathered from the upper portion of the smoke-box, as with the common form of nozzle, but the inner surface acts only on gas drawn from the lower portion of the box and so increases the draught through the lower tubes of the boiler, which otherwise are not so active as the higher ones.

168. Photographs of American locomotives. Presented by Messrs. Burnham, Parry, Williams and Co., 1890. M.2354.

These show four typical American locomotives, as made at the well-known Baldwin Locomotive Works which were established at Philadelphia in 1831, and illustrate types used for four different classes of service ; the dimensions and leading particulars are attached to each.

169. Photographs of locomotives. Presented by Messrs. Neilson and Co., 1890. M.2347.

This is a series of twenty photographs, together with the leading dimensions and particulars, of engines supplied for working the traffic in various parts of the world.

170. Photographs of Russian locomotives. Presented by David Joy, Esq., 1896. M.2927.

These three engines have outside cylinders, and show very clearly the arrangement of the Joy valve gear with which they are fitted.

One engine has six wheels, all coupled ; it weighs 34 tons empty, and 38 tons in working order. The steam pressure is 132 lbs. per sq. in., the heating surface 1,313 sq. ft., the diameter of the cylinders 18·1 in., the stroke, 24 in., the diameter of the wheels 55 in., and the tractive factor 143.

The second engine has six wheels coupled and a four-wheeled bogie ; the tender is on two four-wheeled bogies. The total weight of the engine empty is 52·7 tons and 58 tons in working order. The diameter of the driving wheels is 72 in., the steam pressure 147 lbs. per sq. in., and the heating surface 1,661 sq. ft. The cylinders are compound and have a common stroke of 25·6 in. ; the diameter of the high pressure cylinder is 19·7 in., while that of the low is 28 in.

The third is a four-wheel-coupled engine with a leading four-wheeled bogie ; it weighs 46 tons empty and 50·8 tons in working order. The diameter of the driving wheels is 78 in., the steam pressure 147 lbs. per sq. in. and the heating surface 1,571 sq. ft. The cylinders are compound with a common stroke of 25·6 in. ; the diameter of the high pressure is 18·1 in., and that of the low 26·4 in.

The large head lights and more complete protection for the drivers are required by the local conditions; there is also a complete outside hand-rail right round the sides and front of the engine.

171. Model of London and North Western Railway compound locomotive (working). (Scale 1 : 6.) Received 1896. M.2936.

This shows a compound locomotive arranged on the system introduced by Mr. F. W. Webb in 1881, but the engine represented is of a later type, known as the "Dreadnought" class, and was shown at the Inventions Exhibition in 1885.

The distinctive feature of Mr. Webb's arrangement is that the steam from the boiler first enters a pair of outside high pressure cylinders acting on the trailing axle, while the exhaust from both of these cylinders passes into a single low-pressure cylinder acting on a separate axle. This gives the reduced temperature ranges within the cylinders that result from compounding, and also the advantage of four driving wheels without employing coupling-rods. When starting it is arranged that the engine can work non-compound, the exhaust from the high-pressure cylinders passing directly into the blast pipe, and reduced boiler steam being supplied to the low-pressure cylinder.

The high-pressure cylinders, 14 in. diam., are arranged outside the frames between the leading and middle wheels, with long piston and connecting rods, so that they can drive the crank-pins on the trailing wheels. The low-pressure cylinder, 30 in. diam., is on the centre line and under the smoke-box, and acts on a single crank bent in the central axle. The four driving wheels are each 75 in. diam., the stroke of each cylinder is 24 in. and the area of the single low-pressure cylinder is 2·3 times the combined areas of the two high-pressure cylinders. The valve chests of the high-pressure cylinders are beneath them, and that of the low-pressure is above the cylinder. The valves are all driven by Joy's gear; for the outside cylinders the reversing guides are formed in pairs of circular discs, while for the inside cylinder these guides are formed in a cast steel rocking-shaft. Both gears are reversed simultaneously from the platform by a single lever, but arrangements are provided for separate adjustment when desirable.

The leading wheels are 3 ft. 9 in. diam., and are carried in Webb's radiating axle-boxes, an arrangement by which on entering a curve the lateral displacement of the wheels causes an angular movement of the axle owing to the boxes being carried in a curved guide path. The rigid wheel base is 9 ft. 8 in. and the total wheel base 18 ft. 1 in.

The boiler is of steel with a copper fire-box, and has a water bottom below the fire bars with a small ash door in it, and a front ashpan door and damper. The grate area is 20·5 sq. ft., and the total heating surface 1,400 sq. ft. The working pressure is 175 lbs. per sq. in., but a relief valve prevents the steam to the low-pressure cylinder exceeding 80 lbs. The feed water is supplied by an injector on either side of the platform, delivering above the water level into a pipe which reaches to the middle of the barrel before it dips, so that the feed pipe is heated by the surrounding steam. The tender has space for 5 tons of coal and carries only 1,800 galls. of water, being fitted with Ramsbottom's scoop for taking up water when running (*see* No. 158).

The engine is fitted with a steam brake, having a vertical 9 in. cylinder which applies the blocks to the four driving wheels and to the

six wheels of the tender; a hand-worked screw gear is also provided. The weight of the engine empty is 42·5 tons, and that of the tender 12 tons.

172. Drawings of compound engines on the North Eastern Railway. (Scale 1 : 8.) Lent by T. W. Wordsell, Esq., 1890. M.2330.

Working drawings of both a passenger engine and a goods engine, on the Worsdell and Von Borries system of compounding, are shown.

In these engines two cylinders only are employed, and these are arranged within the frames. To provide room for the large low-pressure cylinder, the cylinders are cast together, and are placed at different inclinations so that they overlap without intersecting. The valve motion is of Joy's radial type, and is reversed by a screw. For starting, in cases when the high-pressure slide valve is completely closed, a starting valve is provided which shuts the communication between the high and low-pressure cylinders, and at the same time allows some live steam to enter the low-pressure cylinder.

The passenger engine has cylinders 20 in. and 28 in. diam. with a common stroke of 24 in., and single driving wheels 91·25 in. diam. The boiler pressure is 200 lbs. per sq. in., grate area 20·7 sq. ft., and the total heating surface 1,139 sq. ft. The weight of the engine in working order is 46·67 tons. The slide valves are arranged on the outside of the cylinders in chests that come through the frames.

The goods engine has cylinders 18 in. and 26 in. diam., with a common stroke of 24 in., and driving wheels 61·25 in. diam., with three axles coupled by external rods. In this engine the slide valves are arranged above the cylinders. The grate area is 17·23 sq. ft., and the total heating surface 1,136 sq. ft.

173. Model of express locomotive of the London and South Western Railway (working). (Scale 1 : 8.) Made by Messrs. T. and C. J. Coates, 1896 and 1899. Plate VI., No. 1. M.2926.

The engine and tender represented were designed and constructed at Nine Elms in 1890, by Mr. W. Adams, for working the express passenger traffic on the London and South Western Railway.

The cylinders are 19 in. diam. by 26 in. stroke, and act on four coupled driving wheels 85 in. diam., exerting a tractive effort of 110 lbs. per lb. of effective mean pressure in the cylinders. Each piston-rod is guided by a single bar guide arranged vertically over it, and in some engines of this class the piston-rod was extended through the cover as a tail rod. The valve gear is of the usual shifting-link construction, giving a cut-off varying from 75 per cent. with full gear, to 17 per cent. in usual running condition; it is controlled from the foot-plate by a reversing screw. The regulator or main steam valve is of the vertical sliding type, and is arranged in a steam dome; at its back is a smaller valve which, opening first, reduces the frictional resistance of the main one.

The boiler shell and the external fire-box are of mild steel, but the internal fire-box is of copper. The tubes are of brass, 1·75 in. outside diam., and 240 in number. The grate area is 18 sq. ft., fire-box surface 122 sq. ft., and tube surface 1,244 sq. ft. To insure complete combustion the fire-box is fitted with a brick arch and a deflector. The grate

bars are of cast iron in two lengths. The blast pipe is of Mr. Adams' "vortex" construction with an area of 14 sq. in. (*see* No. 167). The safety-valves, loaded to 175 lbs. per sq. in., are of Ramsbottom's double type, with an easing lever extending to the cab. The feed-water is supplied from the tender by two injectors, and the engine is fitted with a steam and an automatic brake. The front of the engine is carried on a four-wheeled bogie, with wheels 45·75 in. diam.; the engine and bogie frames are of mild steel plate. The springs of the driving and trailing axles are connected by equalising levers. The total weight of the engine in working order is 48·75 tons.

The tender is carried on six wheels and has double frames with outside bearings; the wheel base is 13 ft. and the wheels are 45·75 in. diam. The brake of the tender is applied by a vertical steam cylinder or by a screw, the screw-rod rising in its guides when the brake is forced on by steam pressure. The water-tank has a capacity of 3,300 gals.; it is fitted with vertical and horizontal tie-bars and angles to give the necessary rigidity, while the supply orifice is provided with a deep strainer which acts as a baffle plate in preventing the upward splash of the water. The tender is coupled to the engine by a central draw-bar and two loose side links, and here there are also two special buffers; at the front end of the tender is a sand-box and tool chest, also a hinged door for closing the opening through which the coal from the top of the tender is raked on to the foot-plate. The weight of the tender empty is 14·3 tons, and it carries 3 tons of coal and 14·7 tons of water.

The total weight of the engine and tender in working order is 80·75 tons, and the normal weight of the train behind them is about 230 tons.

174. Photographs and drawings of tank locomotives. (Scale 1 : 32.) Presented by T. Hurry Riches, Esq., 1898. M.3027.

These tank engines were designed by Mr. Riches in 1890 for the Taff Vale Railway.

The passenger engine has inside cylinders 17·5 in. diam. by 26 in. stroke, and four coupled wheels 63 in. diam., giving a tractive factor of 127. There is a leading four-wheeled bogie, and a pair of trailing wheels with their axle in radiating boxes. The boiler has 19 sq. ft. of grate, and 1,042 sq. ft. of heating surface; the working pressure is 160 lbs. The tank carries 1,500 gallons of water and the bunker 1·5 tons of coal. The weight of the engine is, empty 45 tons, and in working condition 57 tons.

The mixed-traffic engine has similar cylinders and driving wheels; it is, however, six coupled, and has a radiating trailing axle, but no bogie. Its weight empty is 52 tons, and 64 tons when full.

175. Photograph of American express locomotive. Presented by Harold Edwards, Esq., 1899. M.3046.

This shows the leading features of the modern American locomotive, in which the bar frame and outside cylinders with valve chests above them are almost invariably adopted; the front of the engine is fitted with a powerful track clearer or cow-catcher, and the large headlight and bell are added on account of the road not being completely enclosed.

The engine represented, No. 999 of the New York Central and Hudson River Railroad, was shown at the Chicago Exhibition in 1893, and

was stated to have travelled a distance of one mile in 32 secs.; this would be at the rate of 112·5 miles per hour. It has two cylinders 19 in. diam. by 24 in. stroke, and driving wheels 86 in. diam., giving a tractive factor of 100; there are four coupled driving wheels, and a leading four-wheeled bogie with wheels 40 in. diam. The boiler has 260 tubes, 2 in. diam. and 12 ft. long, giving nearly 1,700 sq. ft. of surface, while the heating surface in the fire-box is 233 sq. ft. The total heating surface is nearly 2,000 sq. ft. and the grate area 30·7 sq. ft. The inside diameter of the chimney is 15·25 in., and its top is 14·8 ft. above the rails. In working order the weight of the engine is 55·3 tons and that of the tender 35·7 tons, the total running weight of engine and tender being 91 tons.

176. Drawing of Baldwin locomotive. (Scale 1 : 16.) Presented by Clement E. and C. Stretton, Esqs., 1900. M.3107.

This is a passenger locomotive on the Vauclain system of compounding, fitted with the extended fire-box introduced in 1878 by Mr. J. E. Wootten for burning anthracite coal. It was built at the Baldwin Works in 1893, for the Pennsylvania and Reading Railroad, and has attained a speed of 82 miles per hour.

On each side there is a pair of cylinders, 13 in. and 22 in. diam. by 24 in. stroke, with a common crosshead and connecting-rod; there are four coupled driving wheels 78 in. diam., while the smaller wheels are 48 in. diam.

The boiler barrel is 57·5 in. diam. and contains 324 tubes 1·5 in. diam. by 10 ft. long; the fire-box is 9·5 ft. long by 8 ft. wide, with a grate area of 76 sq. ft., and has 173 sq. ft. of heating surface, the total heating surface of the boiler being 1,435 sq. ft. Owing to the non-flaming character of the fuel employed, fire-box surface has to be chiefly relied on, and an exceptional area of grate is necessary; these requirements are met by raising the grate above the level of the trailing wheels and by spreading it to the full width of the engine. The grate surface is formed by water-tubes and fire-bars alternately, and there is a separate combustion chamber. The firing platform is at the end of the boiler, but the driving cab is arranged on the sides of the barrel. The total weight of the engine in working order is 58·8 tons.

177. Photographs of Winby's locomotive. Presented by Messrs. R. and W. Hawthorn, Leslie and Co., 1893. M.2529A.

Three views are shown of the engine "James Toleman," designed by Mr. F. C. Winby, and constructed in 1893 by Messrs. Hawthorn, Leslie and Co. It has two inside cylinders 17 in. diam. by 22 in. stroke, and two outside cylinders 16·5 in. diam. by 24 in. stroke; the total tractive factor is therefore 143·3. There are two pairs of driving wheels each 90 in. diam., and no coupling-rods, as each pair of cylinders drives one axle. The boiler is peculiar, the barrel not being circular, and the grate extending much further forward than the crown of the fire-box, but the grate area is 28 sq. ft., and the total heating surface 2,000 sq. ft.; the boiler pressure is 175 lbs. per sq. in. The total weight in working order is 61 tons.

178. Model of express passenger locomotive of the North British Railway. (Scale 1 : 16.) Lent by R. St. J. Willans, Esq., 1902. M.3244.

This represents a class of four-coupled bogie locomotive designed about 1895, by Mr. Matthew Holmes, and built at the Cowlairs Works, Glasgow.

The engine has horizontal inside cylinders 18 in. diam. by 26 in. stroke and driving wheels 84 in. diam., thus giving a tractive factor of 100. The valves are placed between the cylinders and worked by the usual shifting link reversing gear controlled from the left hand side of the cab by a vertical screw.

The boiler barrel is 53·5 in. diam. by 10·3 ft. long, and contains 238 tubes 1·75 in. diam. The total heating surface is 1,266 sq. ft., of which the fire-box forms 118 sq. ft., and the grate area is 20 sq. ft. The working pressure is 150 lbs. and it is limited by a pair of safety valves placed on top of the dome and directly loaded by springs.

The front of the engine rests on a bogie having four wheels 42 in. diam.; the total wheel base of the engine is 22·42 ft., of which 9·33 ft. is rigid. The engine is fitted with the Westinghouse brake applied by means of cylinders suspended between the driving and trailing wheels. The weight of the engine in working order is 46·5 tons, of which 31 tons rest on the coupled wheels.

The tender is mounted on six wheels 48 in. diam. with a 12 ft. wheel base; it has outside frames and carries 2,500 galls. of water, while its weight in working order is 32 tons. The total weight of engine and tender in working order is 78·5 tons and the overall length 52·7 ft.

In front of the model is shown a grooved pulley which is used in connection with an endless wire rope employed in assisting trains up the incline from Queen St. station to Cowlairs.

179. Print of American-built locomotive for the Midland Railway. Presented by Clement E. Stretton, Esq., 1899. M.3087.

In 1899 considerable sensation was caused by some of the English Railway Companies ordering locomotives from America, owing to a great increase of the traffic having created a sudden demand for more motive power than the existing manufacturing arrangements on this side of the Atlantic were, under exceptional circumstances, able to meet. In 1840, however, several American locomotives were imported for use on the Birmingham and Gloucester railway, and in our Colonies a considerable number of American engines have long been used.

The engine represented is the first of a batch of thirty ordered from the Baldwin Locomotive Works for the Midland Railway Co., and it generally represents American practice with only slight modifications to meet English requirements. The engine is of the "Mogul" type with outside cylinders 18 in. diam. by 24 in. stroke and six coupled wheels 60 in. diam., so that its tractive factor is 129; the leading wheels are 33 in. diam. and are carried in a pony frame. The rigid wheel base is 14·75 ft. and the total wheel base 22·17 ft. The framing is of the American bar type, and the cab gives much more protection from the weather than the usual English construction; the slide valves are balanced and are driven by the ordinary link motion, through the intervention of rocking shafts.

The boiler shell is 56 in. diam. and of ·625 in. steel plate; the fire-box and stays are of copper. There are 263 tubes 1·75 in. diam., giving 1,247 sq. ft. of heating surface, and the total heating surface is 1,372 sq. ft.; the grate area is 16·6 sq. ft. and the working pressure 180 lbs. The tender is carried on two four-wheeled bogies and has a capacity of 3,000 gallons. The weight of the engine is 44·75 tons and that of the engine and tender 80·15 tons.

180. Drawing of express locomotive of the London and South Western Railway. (Scale 1 : 12.) Lent by Messrs. Dubs and Co., 1901. M.3211.

This is an example of a class of express locomotive designed by Mr. D. Drummond in 1898, and built by Messrs. Dubs and Co. It has inside cylinders 18·5 in. diam. by 26 in. stroke, driving four coupled wheels 79 in. diam., so that its tractive factor is 112.

The slide bars, of which there are four to each cylinder, are entirely supported by a central spectacle plate, which also contains the guides for the valve rods. The valves, which work in a single steam chest between the cylinders, are each made in two parts placed side by side, but have separate ports, and the exhausts of the lower ones pass downward and round the outside of the cylinders. The valve gear is of the usual shifting link type, but is reversed by a steam cylinder checked by an oil cataract and controlled by a small hand lever in the cab.

The boiler barrel is 4·5 ft. diam. by 10·5 ft. long, and contains 280 brass tubes 1·5 in. external diam. The internal fire-box is of copper, and has a curved roof supported by bolts from short brackets suspended from girders riveted to the external crown. The upper portion of the fire space of the box is fitted with an arrangement of water tubes, patented in 1897 by Mr. Drummond, in which straight solid-drawn steel tubes 2·75 in. external diam. and ·125 in. thick are employed. These are arranged transversely in two groups, the front one of thirty-six tubes and the back one of twenty-five, inclining in opposite directions at 5 degrees with the horizontal. Their ends are specially expanded into the fire-box plate, and opposite the ends of each group are large inspection holes through the fire-box shell, closed by hinged doors bolted to cast steel seats and strengthened by internal stays passing through some of the tubes from door to door. These water tubes present 165 sq. ft. of heating surface, while that of the fire-box plating is but 148 sq. ft.; the total heating surface in the boiler is 1,500 sq. ft. and the grate area 24 sq. ft.; the working pressure is 175 lbs. per sq. in. The smoke box is fitted with Mr. Drummond's spark arrester, which consists of a chimney tube, extending down to the top of the blast pipe and having openings in it at the sides and front, into which the gases are directed by baffle plates. The feed water, which is supplied by two injectors at the side of the ash pan, is passed through pipes in the smoke box before entering the boiler.

The engine is supported at the front end by a bogie having four wheels 48 in. diam. at 6·5 ft. centres; the rigid wheel base of the engine is 10 ft. and its total wheel base 23·25 ft. while its weight is 50·4 tons, of which 35·4 tons are carried by the coupled wheels.

The tender has six wheels 48 in. diam. and a wheel base of 14 ft., but some of these engines are provided with tenders carried on double

bogies; the capacity of the tender is 3,500 gals. of water and 4 tons of coal.

The total weight of engine and tender in working order is 91·1 tons, and the overall length 56 ft.

181. Model of compound locomotive, Western Railway of France (working). (Scale 1 : 10.) Made by M. P. Regnard. Received 1903. Plate VI., No. 2. M.3298.

This represents a powerful passenger locomotive designed by M. Clerault and constructed at the Batignolles works of the railway company in 1901. It has four cylinders, six coupled wheels and a leading bogie arranged in a manner introduced in 1885 by M. de Glehn and modified in 1891 by M. du Bousquet.

The engine is of the compound type, as the steam from the boiler first enters a pair of outside high-pressure cylinders acting on one axle and is then exhausted into a pair of low-pressure cylinders acting on a separate axle which is, however, coupled to the first. The cranks of the adjacent high and low-pressure cylinders are placed at 180 degrees with each other, so that the reciprocating masses move in opposite directions and thus nearly balance their inertia stresses while the rotating masses are completely balanced by weights in the wheels. Each cylinder is provided with a separate valve gear, and there are additional starting valves by which the engine can be worked non-compound, the exhaust from the high-pressure cylinders then passing directly into the blast pipe, while reduced steam direct from the boiler is supplied to the low-pressure cylinders. By these arrangements the economy due to compound working is obtained, with good balancing, while, owing to the reduction in the stresses through the work done being divided over four cylinders, it is claimed that the increased amount of mechanism entails no extra wear.

The high-pressure cylinders, 13·77 in. diam., are arranged outside the frames immediately in front of the coupled wheels, and act on the crank-pins of the second pair of these wheels; the low-pressure cylinders, 21·56 in. diam., are placed between the frames under the smoke-box and act on a crank-shaft carrying the leading pair of coupled wheels. The low-pressure cylinders with their valve chest and the boiler cradle are in one casting secured between the frames, while the external high-pressure cylinders are stayed together between the frames by a special casting which also assists in carrying the guide bars. The stroke of both cylinders is 25·2 in. and the area of the low-pressure cylinder is 2·47 times that of the high pressure; the driving wheels are all coupled and 76·4 in. diam.

The valve-chests of all the cylinders are placed above them, those of the low-pressure, however, inclining outward; the valves are of the ordinary flat type and those of the inside cylinders are driven by the Walschaërts' motion, in which a single eccentric is used for each cylinder, while those of the outside cylinders are driven by the same gear, but with a return crank in place of the eccentric; these gears can be linked-up either together or separately by means of a screw reversing gear.

The valves for separating the high and low-pressure cylinders when starting are placed on the high-pressure exhaust pipes and are actuated by a small compressed air cylinder beneath the boiler barrel, while the

steam pressure in the low-pressure chest is limited by a relief valve to 85 lbs. per sq. in., the boiler pressure being over 200 lbs.

The bogie has four wheels, 37·8 in. diam., with a wheel base of 6·56 ft. and is arranged to permit of sliding lateral displacement. The rigid wheel base of the engine is 14·11 ft. and its total wheel base 26·92 ft.; the gauge of the rails is the standard 4·7 ft.

The boiler is of steel, with a copper fire-box, and has a barrel 57 in. diam. by 14·63 ft. long between tube plates. The fire-box is of the Belpaire type, in which the outer shell and the fire-box crown are both flat and directly tied together by screwed stays while long transverse stays connect the flat sides of the upper part of the outer shell. By this method of staying, the usual girder stays are entirely dispensed with and increased steam space is obtained. The back plate of the external fire-box is directly tied to the boiler barrel by longitudinal stays, the number of which is, however, reduced by the addition of heavy stiffening ribs riveted to the flat surfaces. The boiler is provided with 113 tubes of 2·75 in. external diam., but as these are of the internally ribbed type, patented by M. J. Serve in 1885 (*see* No. 283), their total internal surface is 2,149 sq. ft. although their external surface is but 1,217 sq. ft. The tubes are fitted by expanding in the usual manner after the ribs have been cut away near the ends, and they are cleaned after use by a steam jet assisted by occasional scraping.

The grate slopes forward and, to facilitate cleaning, has a hinged dropping portion at the lower end operated from the foot plate. The grate area is 26·4 sq. ft. and the heating surface of the fire-box 131 sq. ft. There is a steam dome containing the regulator, which is of the vertical slide type with a smaller starting slide, and there are two directly loaded safety valves upon the fire-box which limit the steam pressure to 213·3 lbs. per sq. in. The smoke-box is long and has an ash-shoot below; the blast-pipe is provided with a nozzle which is adjustable by two hinged flaps worked from the foot-plate. The chimney expands within the smoke-box into a conical chamber, the bottom of which is formed by a large spark-arresting grating provided with an orifice for the blast.

The feedwater is delivered by a pair of injectors placed on the back of the fire-box; Gresham's sanding apparatus, using compressed air, is provided for the wheels, and continuous lubrication is effected by a pump driven by the valve gear. A special fitting is attached to the boiler with which the several small steam pipes are connected, thus reducing the number of holes made through the boiler shell. The total weight of the engine in working order is 62·5 tons, of which 44·3 tons are available for adhesion.

The tender has six wheels, 44·5 in. diam., spread over a wheel base of 10·5 ft., and the springs of the two rear axles are connected by compensating levers so that the whole load is equally distributed over the six wheels. The tender carries 3,300 galls. of water and 5 tons of coal, and its weight in working order is 36·5 tons.

The coupling between the engine and tender is of the Roy construction tightened up by a ratchet on the screw; oblique cheeks are secured to the tender while the corresponding pieces on the engine form portions of a spherical surface, so that when tightened up the connection possesses flexibility while it restricts the longitudinal and lateral movements. The engine is fitted with the Westinghouse brake apparatus, and has air brakes on the six coupled wheels; the wheels of the tender are similarly fitted, but their brakes can be applied by hand if required.

The total weight of the engine and tender in working order is 99 tons, and their overall length is 56·3 ft.

182. Model of Fell centre rail locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1904.
M.3374.

The use of a central rail and horizontal gripping wheels to increase the adhesion of a locomotive running on smooth rails was first proposed and patented in 1830 by Messrs. C. B. Vignoles and J. Ericsson, while the system was re-invented in 1847 by Mr. G. E. Sellers, who practically tried it in America. The project was revived, however, during the construction of the Mont Cenis tunnel, when Mr. J. B. Fell proposed that a railway on the "central rail" system should be built over the pass, and in 1863–9 he secured patents for such locomotives. After experiments had been carried out on the Cromford and High Peak Railway and at Mont Cenis, the line was constructed and opened in 1868, but it was not financially successful, its life ending on the opening of the tunnel in 1871. The railway was 48 miles in length, laid along the public road to a gauge of 3·61 ft. (1·1m.), having a maximum gradient of 1 in 12 with a minimum radius of curvature of 2 chains; the central rail was laid on all gradients steeper than 1 in 25. The system was afterwards tried in Brazil. In 1879 an incline of 1 in 15 was constructed in New Zealand and successfully worked.

The model represents the framework and gearing of one of the Mont Cenis engines built in 1867 by Messrs. Gouin and Co., Paris; it is shown mounted on a gradient of 1 in 12.

The engine was carried on four coupled wheels 28 in. diam. with a wheel base of 7·08 ft. There were two horizontal cylinders 16 in. diam. by 16 in. stroke, fixed between the frames in the usual way, with the valve chests between them. The valves were driven by outside eccentrics, link motion, and rocking shafts. The tractive factor was 146·3. At the middle of the engine, between a pair of transverse stays, were situated two sliding frames, one on each side of the centre line; each of these carried two vertical shafts, having at their upper ends overhung cranks, while to their lower ends were fixed the horizontal wheels, 28 in. diam., which were pressed inward so as to grip the central rail, by means of springs and cross beams actuated by a right and left hand screw operated from the footplate. The shafts on each side of the central rail were coupled by rods at the top and bottom, and were directly driven by the pistons through connecting rods moving in a horizontal plane, while the motion was communicated to the carrying wheels through rocking shafts and levers which drove outside connecting rods attached to crank pins in the wheels. In later engines, however, it was found necessary to couple the horizontal wheels on opposite sides of the central rail by linkwork or spur gearing, so as to keep them in correct phase with one another. The boiler had a barrel 3 ft. diam., and 9·33 ft. long, with a heating surface of 654 sq. ft. and a grate area of 13·5 sq. ft.; the steam pressure was 120 lbs. per sq. in. When descending inclines the engine was retarded by brake blocks on the carrying wheels and also by means of slipper blocks gripping the central rail.

The weight of the engine in working order was about 20 tons, while a similar pressure could be applied to the central rail, thus doubling the adhesion; in general working the engine hauled a load equal to

its own weight up a gradient of 1 in 12 at a speed of 10 miles an hour. The double-headed central rail was laid on its side and supported on chairs formed of bent wrought iron bars which were bolted to longitudinal sleepers laid upon and secured to the transverse ones.

183. Model of Riggenbach rack locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1904.
M.3375.

The rack and pinion as a means of locomotive haulage was patented in 1811 and used in 1812 by John Blenkinsop (*see* No. 122). In 1852 the system was revived with a central rack and applied to an incline of 1 in 16·5 at Madison, U.S.A. In 1857 Mr. S. Marsh proposed a similar line with a maximum gradient of 1 in 3 at Mount Washington, U.S.A., and this was constructed in 1869. The system was taken up in Europe by Mr. N. Riggenbach, who patented improved appliances in 1862; in 1870 he constructed the Rigi railway in Switzerland, which has a maximum gradient of 1 in 4; this was followed by several others, one of which runs up the Kahlenberg, near Vienna. This line, which was constructed in 1874, was laid to a gauge of 4·71 ft. and had a maximum gradient of 1 in 10; the ladder rack was laid midway between the rails. The model represents the framework and gearing of one of the locomotives built for this line at the Swiss locomotive works, Winterthür. It is shown mounted on a 10 per cent. incline.

The engine was carried on four wheels, 26 in. diam., with a wheel base of 10·17 ft. There were two horizontal outside cylinders 13 in. diam. by 17·72 in. stroke, which drove a countershaft having a pair of pinions fixed on it; below this was a shaft carrying a toothed wheel which geared with the rack, and to each side of it was bolted a wheel gearing with the pinion above. The tractive factor was 173. The boiler was of the ordinary locomotive type with a heating surface of 582 sq. ft. and a grate area of 10·6 sq. ft.; the steam pressure was 132 lbs. per sq. in.

The engine, with its chimney at the lower end, pushed the carriages up the incline, there being no couplings. The descent was regulated by three methods of braking: (1) by a strap brake on one of the crank discs, (2) by a toothed pinion on the back axle gearing with the rack and fitted with drums and brake blocks, (3) by the compression in the cylinders of air from the outside, drawn through the exhaust ports and expelled through a special regulating valve. Guards were provided to prevent derailment. The engine carried 220 galls. of water in tanks and 25 cwt. of coal in the bunkers; its weight in working order was 19·44 tons and its ordinary load 42 tons.

The permanent way consisted of flat-footed rails weighing 40 lbs. per yd., spiked to transverse sleepers. The rack had a pitch of 3·72 in., the teeth being formed of wrought iron bars of trapezoidal section with oval ends riveted into the webs of a pair of 4 in. by 2·4 in. channel irons, placed back to back 5 in. apart. The rack was in lengths of about 10 ft. joined by fish plates and bolted to the sleepers: its weight was 111 lbs. per yard.

184. Model of Abt rack locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1904. M.3376.

The Riggenbach ladder rack as used on most of the early mountain railways had several defects, and to overcome these Mr. R. Abt patented

in 1882 an improved form of rack consisting of narrow rectangular bars having teeth cut in them, and placed vertically on chairs. These bars were arranged in two or three lines near together with the teeth stepped, and a pair of stepped pinions on the locomotive, out of phase with one another, geared into them, thus ensuring smoothness of motion. The first railway on this system was constructed in 1884–6 at Blankenburg in the Harz Mountains and the system has since received wide application. In 1894–6 a tourist line was constructed on Mount Snowdon; it is 4·67 miles long with a rise of 3,140 ft., its average gradient being 1 in 7·83 and the maximum gradient 1 in 5·5; the gauge is 31·5 in. and the minimum curve is of 4 chains radius. The model represents the framework and gearing of one of the locomotives built at the Swiss locomotive works, Winterthür, for use on this line, together with the permanent way on a gradient of 1 in 5·5.

The engine is carried on six wheels; the four leading ones are 25·71 in. diam., running loose on their axles; the trailing wheels, 20·47 in. diam., are arranged on a Bissel truck; the rigid wheel base is 4·43 ft. and the total 9·85 ft. There are two horizontal outside cylinders, 11·81 in. diam. by 23·62 in. stroke, placed above the footplate midway along the engine, with the valve chests above them. The piston rods are continued forward to the crossheads and the motion is communicated to cranks on the central axle through connecting rods and rocking levers pivoted low down on the frame. The two leading axles are coupled by rods and each carry a double pinion gearing with the rack; these consist of toothed rings, connected with discs forged solid with the axle by means of internal springs allowing a slight circumferential movement, thus compensating for any irregularities in the rack teeth. Each pinion has fifteen teeth and a pitch diameter of 22·56 in., the teeth of one pinion ring being opposite the spaces of the other. The tractive factor is 146. The pinions are held in position laterally by grooved brake drums on each side bolted to the axle discs. The engine frames are outside the wheels and are strongly braced by vertical and horizontal cross stays; springs are provided at the driving and trailing wheels only. The boiler has a heating surface of 397 sq. ft. and a grate area of 10 sq. ft.; its axis is inclined at 1 in 11 to the rails; the steam pressure is 200 lbs. per sq. in.

The engine pushes its load up the inclines, there being no couplings, whilst on the descent three methods of braking are available. These consist of (1) brake blocks gripping the drums on the driving axles, (2) an automatic gear which applies a steam brake to two of the drums when the speed of the engine exceeds 5 miles an hour, and (3) by the compression of air in the cylinders, air from outside being drawn in through the exhaust ports, compressed, and expelled through a special regulating valve. The latter method is generally used and water jets are introduced into the cylinders to cool the air. Water is carried in side tanks having a capacity of 440 gallons, while the coal bunker holds 10 cwt.; the weight of the engine in working order is 17·22 tons, its load of 18·5 tons being conveyed at a speed of 4 to 5 miles an hour.

The rack bars are cut to form in one operation in a milling machine by a gang of cutters; they are 70·7 in. long, and have fifteen teeth of 4·72 in. pitch and 1·97 in. depth; the thickness is ·98 in. on gradients steeper than 1 in 9 and ·79 in. on flatter gradients. The bars are arranged so as to break joint and are bolted at the middle and ends to rolled steel chairs, weighing 12 lbs. each, which are bolted to the transverse sleepers. The rails are flat-footed and weigh 41·25 lbs. per

yard; the sleepers are of steel of trough section with turned-down ends, 6 ft. long and spaced 35·45 in. apart; the rails are fastened by clips and bolts. At intervals of 50 to 150 yards, according to the gradient, vertical iron joists, set in concrete blocks, bear against the sleepers and act as stops to prevent the track creeping downhill.

185. Model of an electric locomotive (working). (Scale 1 : 4.) Lent by Messrs. Beyer, Peacock, and Co., 1894. M.2561.

This electric locomotive is designed to receive its current from a contact piece sliding on a central rail, or from an overhead conductor. The chief object of the arrangement is to dispense with spur gearing and yet keep the armatures well above the mud and dust, which, owing to the small driving wheels necessary, are found in the neighbourhood of the axles.

There are two armatures, and each is connected by two overhanging cranks and diagonal coupling-rods with one of the driving axles, so that the axles are driven independently. The axle-boxes slide in inclined guides, so that the pull of the coupling-rods shall not be felt on the springs. The armatures are in a single magnetic circuit, and the field windings are arranged in one horizontal and two vertical coils below the platform. A screw brake is provided for stopping, but the starting levers and resistances are not shown.

The model is carried on friction wheels which can be rotated from outside the case, so that the motion of the connecting-rods may be followed.

186. Steam tramcar. (Scale 1 : 8.) Contributed by Mrs. Grantham, 1876. M.1935.

Mr. J. Grantham in 1871 patented a steam car in which the machinery was below the floor and two vertical boilers were on opposite sides of the car, so as to leave a clear passage from end to end. The exhaust steam was condensed in exposed pipes; the boilers were fired by a screw conveyor; and the whole of the machinery and the brakes were controlled from either end of the car by one man.

In 1872 a car on this plan was made, 30 ft. overall and accommodating twenty inside and twenty-four outside passengers. Each of the boilers was 4·33 ft. high by 18 in. diam. and fitted with Field's tubes; the grate area was only 1·2 sq. ft., while the pressure was 90 lbs. The two cylinders were 4 in. diam. by 10 in. stroke and directly drove wheels 30 in. diam., so that the tractive factor was 5·33; the axles were 10 ft. centres and the total weight empty 6·5 tons. The car, after being tried successfully on a railway, was placed in 1873 on the tramline between Victoria Station and Vauxhall, but it ultimately failed owing to deficiency in boiler power and difficulties in firing; it was, however, the first steam tramcar that worked in England.

The model shows additional features patented in 1872; the driving wheels are flangeless and the axles of the other wheels swivel, so as to render the car dirigible for use on common roads, also these wheels are loose on their axles; for use on rails there are two axles with flanged wheels (broken off), which can be lowered by levers till they bear on the rails. The double gates at either end of the car are for checking the fares.

The Grantham car, after being modified by Mr. E. Woods, continued in use on the Wantage tramway till 1881.

STEAM ENGINE DETAILS AND ACCESSORIES.

Although these details are grouped as a separate section many of them will be found fully represented in the various complete engine models shown, and to these, references will be given without a repetition of the description.

Valve Gears.—The simple plug valves used in working Savery's steam pumping machine of 1698 were turned in their correct order, each about four times per minute by an attendant. Newcomen's engines were similarly worked, but by 1712 some had an automatic valve gear and since then all engines have been arranged to perform their own steam distribution. The Newcomen and Watt engines had vertical drop valves lifted and lowered by levers moved by a tappet rod, and locked in position by latches. In 1785 Murdock invented the long D valve with one flat face sliding on a face on the cylinder side through which were ports leading to the two ends; in 1800 he introduced, in place of the previous tappets and cams, an eccentric with straps for moving the valves; this invention, together with the modification of his slide introduced by Murray about 1802, and known as the locomotive valve, have become almost universal for all but the largest engines.

Engines that were required to run at intervals in opposite directions were at first fitted with a single loose eccentric, from which the motion was conveyed to the valve stem by a forked lever. When the engine was to be reversed this forked lever was lifted out of gear, and the valves worked by hand till the eccentric engaged with a second stop corresponding with the opposite motion of the engine. The fork or "gab" was then allowed again to engage with the valve stem, so that the motion of the engine would be continued as before, but in the reverse direction. With the early locomotives, as will be seen on the "Rocket," there were two eccentrics, and two of these gab levers, since there were two cylinders, and it is recorded that at a high speed the levers on the "Rocket" were inclined to jump out of gear. In 1842 William Howe, a fitter in the employ of Messrs. R. Stephenson and Co., invented an arrangement of valve gear that was at once adopted, and still remains the most usual device for reversing an engine or for varying the rate of expansion, the latter being an equally important property of the invention. He employed a backward and forward eccentric for each cylinder, as already used, and connected the rods of each pair by a curved link, while by a simple shaft and lever it was arranged that the link could be moved so that an adjustable amount of the motion from either eccentric could be transmitted to the valve rod. This form of link motion is generally known as Stephenson's shifting link. Sir D. Gooch introduced a link motion in which the link was held almost stationary

by a swinging lever, and the valve rod terminated in a swinging arm which could be moved into that portion of the link giving the motion required. Allan combined these two forms in his straight-link motion in which both the links and the valve rod are moved, an arrangement that somewhat reduces the vertical height required.

Mons. E. Walschaërts in 1844 introduced a valve gear in which only one eccentric was used, but it made little progress until 1859, when the eccentric was displaced by a return crank. An identical arrangement of this valve motion was independently invented and introduced in 1849 by Herr E. Heusinger von Waldegg, and hence it is sometimes known by his name. J. W. Hackworth in 1854 introduced another form of single eccentric gear, the reversal being obtained by altering the inclination of the slot in which a block, attached to the eccentric rod, works, while the valve rod is attached to the outer extremity of the eccentric rod. Joy, in 1880, introduced a radial valve gear, the motion being derived from a lever attached to the connecting-rod, and the reversal given by a slot of variable inclination as in Hackworth's gear.

With the object of obtaining a quick but easily variable cut off a large number of so-called "expansion gears" have been introduced of the "trip" class in which the steam admission valves close when a catch under the control of the governor is released, the exhaust valves being independently worked by a separate eccentric. By these or other gears the degree of expansion at which the engine works is continuously adjusted to suit the work being done instead of the speed being controlled by throttling the steam supply.

Governors.—In the early Cornish pumping engine the interval of rest between a double stroke was determined by a balanced tank into which water was continually running from an adjustable orifice; when the tank was nearly full it automatically capsized and delivered its water in a cataract, at the same time moving the valve gear. The later "cataract" or fluid controlled gears have only a plunger which sinks at a speed determined by the extent to which a regulating valve is opened.

For regulating the speed of his rotative steam engine Watt adapted the centrifugal governor which had already been applied to the regulation of the speed or fineness of grinding of both wind and water mills. His arrangement consisted of a revolving vertical spindle carrying two dependent swinging levers provided at the lower ends with heavy metal balls, thus forming a balanced conical pendulum, the vertical angle of which would increase with the speed of rotation; by an arrangement of levers this movement of the swinging arms was transmitted to a valve in the steam pipe which throttled the supply of steam, so moderating the fluctuations of the engines under varying conditions of load. Obviously the governor did not maintain constant speed in the engine, but merely reduced the otherwise great variations that would follow an increase or diminution of the steam pressure or the resistances. The variation in fluid resistance with an increase in speed has frequently

been tried as a means for regulating the speed of engines, but up to the present time some form of centrifugal governor is the most usual arrangement.

Watt's governor was a very large piece of mechanism, often running but little faster than the engine. Porter introduced the first great improvement by loading the governor with a weight which, while tending to pull down the balls, did not increase their centrifugal action. This enabled the governor to be run at a high speed, and so rendered it as sensitive as could be desired to any variation of the engine's speed. The modern governors all embody this principle, but frequently springs instead of weights are introduced to supply the closing power, and give the resistance required by the high speed necessary for efficient governing.

Throttle Valves.—The throttle valve employed by Watt consisted of a disc placed in the steam pipe and capable of rotating with a spindle which passed across the steam pipe, and along the diameter of the disc. Such a valve is nearly in equilibrium, and therefore requires but little power from the governor to close it, but it is not very tight or convenient to construct, and so in modern governors a form of double beat equilibrium piston valve is generally adopted.

Lubricators.—Examples of lubricators for revolving shafts and general mechanism will be found classed with shafting and pedestals, but for the steam engine, in addition to these, a special form of lubricator is required to supply a certain amount of unguent to the inside of the cylinder, slide valve faces, etc. This is generally done by allowing the steam to carry in with it a minute quantity of the lubricant in the form of spray which becomes distributed on the free surfaces, or it may be allowed to drop directly into the cylinder. The chief object aimed at in modern improvements in such fittings is to economise the oil as much as possible—since it has been stated that in some small engines the cost of lubrication exceeded that of the fuel.

A method of regularly introducing a small quantity of oil into the cylinder is that followed by the displacement lubricator in which condensed steam drops into the oil receptacle, so causing the lubricant to overflow into the requisite channel. An extension of this plan forms what is known as the sight-feed lubricator in which the drops of oil displaced ascend through a closed tube containing water, so that the rate of feed can be seen and the number of drops admitted per minute can be counted and adjusted.

Piston and Piston Rod Packings.—The object of applying packing to steam engine pistons is to prevent the passage of steam between the cylinder and piston, due to imperfect workmanship and the impossibility of making the piston work tightly in the cylinder in consequence of the friction that would thereby be produced. In early engines, with a low temperature and pressure of steam, hemp packing was found to work well enough, but with the higher temperatures of high-pressure steam, metallic packing is now always used for pistons. In a patent of 1797, the Rev. Edmund

Cartwright described what is probably the first metallic piston packing and for many years his arrangement was but slightly modified. In modern packings, however, considerable attention is paid to the attainment of uniformity of radial pressure and to the avoidance of leakage between the sides of the rings and the piston.

For piston rods, the packing at one time generally used was in the form of woven fibrous material often mixed with plumbago, soapstone, or similar lubricant. Special arrangements of rings and springs have, however, been successfully introduced, and complete metallic packing is now commonly used for all large glands.

Condensers.—Until Watt introduced the separate condenser, steam had been condensed by a jet or spray of water projected upward in the vertical cylinder, and as during the steam stroke some blowing through took place, no trouble was experienced from accumulated air. With Watt's arrangement, however, the necessity for a special pump to remove both air and water was at once seen and provided for, and this so completely that the construction of his jet condenser and air pump have never since been materially improved. Watt saw also that if he could separate the cooling water from the condensed steam the size of the air pump and the power it absorbed would be reduced, and he accordingly experimented with a surface condenser in which the water was within numerous small tubes and the exhaust steam surrounding them just as now almost universally arranged. Difficulty in obtaining sound tubes and in fixing them led to the abandonment of the surface condenser till 1833–7, when it was successfully reintroduced and extensively manufactured by Samuel Hall.

When cooling water is scarce, surface condensers are now frequently built with exposed tubes kept moist by water trickling over them. The evaporation of this external water carries off the heat so efficiently that only about one twentieth part of the water necessary with an internal circulating system is consumed. If space is available, however, the condensing water is generally cooled in large shallow ponds and sometimes the cooling is hastened by distributing the water over brushwood so as to increase the surface exposed to evaporation.

The "ejector condenser" invented by Mr. Morton is a compact arrangement of the injector class by which the energy of the exhaust steam carries it together with its condensing water and air out of the apparatus with such velocity as to maintain a considerable degree of exhaustion or vacuum in the exhaust pipe without the assistance of any mechanism. The discharged water if led to a cooling pond is ready for use again.

Dry surface condensers, composed of small tubes, have been used on the top of tram-car engines, etc., but they only save feed water and prevent annoyance from the exhaust steam; the degree of vacuum obtainable not being worth consideration, such condensers are seldom closed to the atmosphere,

Intermediate Receivers.—These are a necessity between the cylinders of compound engines when the cranks are at right angles; it is probable, moreover, that their introduction does not detract from the efficiency of the engine, while it gives greater facility for starting, the dead centres being covered. The efficiency of the compound engine is stated to be improved by the practice of heating the steam, while in the intermediate receiver, by jacketing this vessel with boiler steam, as adopted by Mr. Cowper in his "hot-pot."

VALVES AND VALVE GEAR.

187. Sectional models of steam engine slide valves (working). Made in the Museum, 1902. M.3263.

This series of eight models shows various modifications that have been employed in this type of valve since its original introduction by William Murdock between 1781–6 in his models of a steam carriage and an oscillating engine (*see* Nos. 46 *and* 108).

As a sliding valve may continue its movement after it has closed any particular passage which it controls, it may be so arranged as to open or close other passages, simultaneously or otherwise, and thus combine the duties of several valves. Owing to this feature a single slide valve replaced the four beat valves which were originally necessary in the early double-acting steam engines, and this simplicity, combined with quietness in working, has since led to the general adoption of the slide valve in nearly all classes of steam engine.

The valves illustrated are:—long D, short D, common or locomotive, piston, double-ported, Trick's, Church's and Hackworth's, details of which will be found attached.

188. Sectional models of steam engine slide valves for variable expansion (working). Made in the Museum, 1903. M.3297.

In order to adjust the work done in steam engine cylinders to suit the variations in the load, two methods are practicable; the first and simplest is to reduce the pressure in the steam chest, by throttling, when the load is below its maximum amount; the second and more economical method is to alter the fraction of the stroke during which steam is being admitted, and leave the completion of the stroke to be performed by this steam while expanding. For this latter system of working many devices have been employed, usually involving some form of valve arranged on the back of the main valve and so actuated by adjustable gearing as to cut off the steam on its way to the main valve.

Such expansion slide valves first came into extensive use about 1840 in the locomotive, the gab reversing gears then employed not permitting of any variation in the point of cut-off; they, moreover, continued in use on locomotives in America and on the Continent for some years after the introduction of the link motion which has now so completely superseded them. For the slow running non-compound marine engines, in which a cut-off earlier than half-stroke was generally required, the excessive compression given by the link-motion, although advantageous

for high piston speeds, was found to be inconvenient so that the separate expansion valve was generally retained until, with the use of direct-acting screw engines, the speeds increased. It was, however, on the non-reversing stationary engine that these expansion arrangements were most extensively adopted, and further developed by being rendered automatic under the control of a centrifugal governor.

A variable expansion valve usually consists of a main slide valve, controlling the admission, release, and compression; and a separate cut-off valve, working either on a separate face or on the back of the main valve, controlling the cut-off only, by shutting off steam from the main valve. The main valve is driven by an eccentric and has little lap, cutting off the steam after about ·75 of the stroke, while the cut-off valve is driven by another eccentric set considerably in advance of the main one. The variation of the point of cut-off is effected by altering either the lap, travel, or advance, of the expansion valve, and the range of the period of admission generally provided is from 0 to ·75 of the stroke.

The six models show the construction of the leading types of expansion slide valve that have been practically employed, and they are so arranged that they can be worked and adjusted from outside the protecting glass case.

The valves illustrated are :—Back-plate, Meyer's, Piston, Rider's, Hartnell's, and Paxman's, details of which will be found attached.

189. Models of balanced slide valve. (Scale 1 : 4.) Presented by Druitt Halpin, Esq., 1901. M.2513.

In this arrangement, which was patented by Mr. James Smart in 1870, the valve is of the locomotive type, but has a small steam chest cast with it at each end. It works steam-tight between V-shaped side guides, through a port in the upper of which steam is admitted to the valve chests, while the lower one, which is also perforated, is connected with the drain cocks. One of these guides is made self-adjusting by springs, so as to keep the surfaces in contact, since owing to there being no surrounding steam chest, the only pressure keeping the valve to its face is that due to the action of the steam upon the difference between the internal back and front areas.

One model shows a cylinder fitted with this valve, while the other, together with a drawing, represents a pair of these valves in the chest of an inside cylinder locomotive in which, however, there would be no steam pressure. The arrangement was ultimately abandoned through the difficulty in maintaining the surfaces steam-tight, owing to the distortion which took place when heated.

190. Model of balanced slide valve. (Scale 1 : 8.) Lent by H. P. Holt, Esq., 1879. M.2511.

This is a section of a slide valve fitted with the form of relief frame patented by Mr. W. Dawes in 1869.

The frame slides upon a planed surface on the inner side of the steam chest cover, and fits around the top of the slide valve. The connection between the frame and the valve is made by a plate of steel or bronze, about ·05 in. thick, so arranged as to leave a considerable amount of elasticity while securing a steam tight joint between the valve and its frame.

Another form of relief frame may be seen on the engines of S.S. "Lopez" in the Marine Engineering Section.

191. Motion diagram of valve gear. Contributed by J. Seaward, Esq., 1860. M.334.

This shows in outline the cylinder, entablature, and standards of a vertical direct-acting paddle-wheel engine, probably of the "Gorgon" type. On one side the cylinder is shown fitted with a long D-slide valve worked, through a rocking shaft, by a single loose eccentric; on the other side is shown a short D-slide valve, with relief frame on its back, similarly driven.

It is probable that this model was made for comparing the action of the valves then in use with that of the type advocated by Mr. Seaward and shown in No. 192.

192. Motion diagram of Seaward's valve gear. (Scale 1 : 10.) Presented by Messrs. Bullivant and Co., 1902. M.1648.

This shows a section of the cylinder, standards, and entablature of the engines fitted by Messrs. Seaward and Capel in 1837 in H.M.S. "Gorgon"; the general arrangement of these engines is shown by a model in the Marine Engineering Section, where the leading particulars are also given.

The cylinder shows an early application of the system of separate steam and exhaust valves to each end of the cylinder, for the purpose of minimising clearance and exposed surface, in the way patented by Mr. Samuel Seaward in 1834; Watt and Murdock had previously adopted separate valves, but theirs were of the drop type. Each of the valves shown is a flat plate in a separate chest, the two steam valves being at the ends of one side of the cylinder and the two exhaust valves opposite them. The steam valves are hinged to their common valve rod, and are free to leave their faces, should water accumulate in the cylinder; the exhaust valves, however, work on faces formed on their chests. The four valves are worked by two adjustable bell-cranks, rocked by a single eccentric on the crank-shaft. Considerable economy in fuel was shown by engines fitted with this gear, and it was extensively adopted in the Navy.

193. Motion diagrams of Seaward's valve gear. (Scale 1 : 10.) Contributed by J. Seaward, Esq., 1860. M.335–6.

The first represents the arrangement adopted by Messrs. Seaward and Capel in their atmospheric engine, patented by S. Seaward in 1838.

Separate steam and exhaust valves, of the plate type introduced by Mr. Seaward, are employed, but the cylinder being open-topped, only two valves are required. These are worked by connected and adjustable bell-cranks driven by a single loose eccentric, which, however, is not shown in the model.

The second shows a modification of the arrangement of engine valves, patented by S. Seaward in 1834, and adopted by Messrs. Seaward and Capel in 1845, in the engines of H.M.S. "Avenger," a steam frigate of 650 H.P. It differs from that of the "Gorgon" class in having a cam on the crank-shaft, in place of an eccentric. The cam is stepped, so

that different grades of expansion can be attained, and against it are pressed two rollers carried on bell-cranks, by which the valves are moved; each roller, however, simultaneously actuates the steam valve at one end of the cylinder and the exhaust valve at the other.

194. Model of reversing gear. (Scale 1 : 10.) Woodcroft Bequest, 1903. M.1836.

This is a model of the driving gear of an inside cylinder locomotive, fitted with a reversing arrangement patented by Messrs. Ogilvie and Richardson in 1858.

The slide valve of each cylinder is driven by a single eccentric, and the reversing is performed by a slide valve, moved by a lever from the foot plate, and situated in the main steam pipe. Steam and exhaust pipes proceed from the valve chest of each cylinder, and by the hand-moved valve these steam and exhaust passages are interchanged.

This gear does not permit of expansive working, and is inferior to the link motion, but for certain purposes is more convenient. Some steam steering gears reverse in this manner.

195. Model of valve gear. Presented by Thomas Silver, Esq., 1869. M.1185.

This is a valve gear designed by Mr. Silver, showing a peculiar arrangement for driving a slide valve from an eccentric, with a means of reversing the motion. Motion is given to the slide valve by the disc, which is oscillated by the eccentric. By raising or lowering the link, the motion for the valve is taken from above or below the centre of the disc, the motion in one case being the reverse of the motion in the other. It is not possible with this motion to give lead to the valve in both directions.

196. Diagram model of expansion valve gear. (Scale 1 : 3.) Contributed by R. Bodmer, Esq., 1857. M.15.

Besides representing a method of completely balancing the reciprocating parts of a locomotive (*see* No. 146), the model shows the application of a right and left-handed screw thread on the valve stem as a means of changing the point of steam cut-off by altering the amount of valve lap. The slide valve has a back cut-off plate in two pieces, as proposed in 1842 by Herr J. J. Meyer, of Mülhausen. Mr. J. G. Bodmer had, however, in 1841 patented the application of a right and left-handed screw to an automatically varied expansion gear, arranged as an adjustable piston-valve in a separate chest at the back of the ordinary valve, and in a patent of 1843 he proposed the arrangement shown in the model as a method of carrying out his earlier invention.

197. Original model of link motion reversing gear. Lent by William Howe, Esq., 1893. Plate VI., No. 3. M.2547.

This wooden model was made by William Howe, of the Forth Street Works, Newcastle, in 1842, to illustrate his invention of the link motion. It was submitted to Stephenson, who at once tried it on a locomotive (No. 359) then being built for the North Midland Railway Co. Since that time it has remained the most popular form of reversing gear,

partly through the ease with which it permits the point of cut-off of the steam to be varied—so reducing the consumption by allowing the steam to work expansively. The construction is described in connection with the larger model, No. 199.

198. Model of reversing-link. Lent by William Howe, Esq., 1893. M.2548.

This is a model in wood of a link and block invented by William Howe in 1848, and fitted to a 36 in. by 6 ft. winding engine at Clay Cross in 1854. The object of the arrangement is to permit of the wear of both link and block being taken up. Each link consists of two bars connected at the ends, and the block is in halves, each half also containing one half of the pin. The valve-rod terminates in a strap end which, when its cotter is tightened, closes on to the block-pin, and by so doing also closes up the block.

199. Model of Howe's link motion applied to a locomotive. (Scale 1 : 2.) Lent by T. Jeffrey, Esq., 1870. M.1829.

This is a working model of what is usually known as Stephenson's link motion, as arranged for the reversing and expansion gear of locomotive engines; it shows a section through the cylinder, piston, slide-valve, and ports, so that its effect upon the working of the valve can be observed. There are two eccentrics on the axle, one set in the correct angular position for going forward, and the other for going backward, and these are connected by rods, one to each end of a curved link, in which slides a block attached to the valve rod. The link can be raised or lowered by the reversing lever, and thereby bring either end of it to act upon the valve rod, so that the valve receives motion from one eccentric or the other. By fixing the lever at intermediate positions, however, the valve is caused to receive a combined motion from the two eccentrics, equivalent to that from a single eccentric having a shorter travel and a greater advance, the effect of which is to cause an earlier cut-off in the cylinder.

200. Model of Gooch's link motion (working). (Scale 1 : 4.) Made in the Museum, 1901. M.3139.

This gear, known as the stationary link motion, was invented in 1843 by Sir Daniel Gooch, Bart., and employed by him on the Great Western Railway. The actual arrangement represented was that on a locomotive built in 1847, and the model shows a horizontal section through one of the cylinders, with its piston, slide-valve, etc., together with the crank and eccentrics. With this gear, constant lead is secured for all degrees of cut-off owing to the link being curved to a radius equal to the length of the rod connecting the block with the end of the valve-rod; this radius rod, however, makes the overall length of the gear greater than that with the shifting link. The link itself is suspended from a fixed point, and swings nearly horizontally, the point of attachment usually being at the centre of the link in engines that frequently run reversed. The eccentric rods are attached one to each end of the link, and the linking-up is effected by altering the position of the block in the link by the usual reversing lever.

201. Model of Allan's straight link motion. (Scale 1 : 2.) Presented by **A. Allan, Esq., 1862.** **M.860.**

This is a working model of the link motion, patented by Mr. Allan in 1854, for the valve gear of locomotives. One eccentric is set in the correct angular position for forward motion, and the other for backward motion of the engine. The reversing lever shifts both the link and the block at the same time, instead of shifting the link only, or the block only, as in former link motions. By this arrangement the link can be made straight; also the vertical height required by the gear is reduced.

202. Model of Walschaerts' valve gear (working). (Scale 1 : 4.) Made in the Museum, 1901. Plate VI., No. 4. M.3175.

In this valve gear the motion for the valve is derived from that of a point describing a circular path round the crank-shaft combined with that from another point receiving a reduced reciprocating movement from the piston; the former component, which by a curved link can be varied and reversed, enables the grade of expansion to be altered or the engine to be reversed; the other component gives the lead, which is constant for all grades, the distribution being, therefore, rather better than that obtained with the ordinary link motions.

The original form of this gear was introduced in 1844 by Mons. E. Walschaerts, of the Belgian State Railways, but it had an unnecessarily complicated arrangement of the link; he had corrected this before 1848 and so brought the gear to its present form except that he still used one eccentric.

Although from its introduction this gear was occasionally used and was generally known to give an excellent steam distribution, it made but little progress till after 1859, when, on some outside cylinder Crampton engines, built for the Northern Railway of France and fitted with it, the single eccentric hitherto retained was displaced by a light return crank, as shown in the model, thus avoiding the use of eccentrics. As thus simplified, the motion has been generally adopted in Belgium since 1860, and in Germany since 1875; nearly all the modern Continental locomotives now have their valves actuated in this manner.

The model shows the gear as arranged on an engine, built about 1883 for a French railway; the cylinders are 17·3 in. diam. by 25·6 in. stroke and drive four coupled wheels 79·5 in. diam. The slide valves are of the piston type, placed above the cylinders, which, as in most Continental locomotives, are outside the frames. Each valve is driven by a lever, the bottom end of which is connected with the crosshead and an intermediate point close to the top end with the valve spindle. The top end is connected with a radius-rod, whose other end fits in a curved link, within which its position is adjustable by the reversing lever. This link is rocked by a pin on a return crank from the main crank pin and 90° behind it. By this arrangement the motion of the valve spindle is compounded of two motions, one derived from the crosshead, giving the lead, and the other from the link rocked by the eccentric pin, giving a motion corresponding to that from an eccentric 90° in advance of the crank pin; but this motion is capable of reduction and reversal by moving the end of the radius rod in the rocking link. The details of the gear represented are:—travel, 5·05 in.; outside lap, 1·18 in.; lead, ·2 in.; and maximum opening to steam, 1·34 in.

This valve motion is shown on the Fairlie locomotive (*see* No. **162**), on the four-cylinder compound locomotive (*see* No. **181**), and also on the compound marine engines of the P.S. "Princesse Henriette" (*see* Marine Catalogue).

An interesting modification of this gear was devised in 1868 by Prof. A. Stévart for application to an engine with two cylinders placed either in planes at right angles working the same crank, or in the same plane on cranks at right angles; from the crosshead of one cylinder is obtained that part of the motion for the valve of the other usually derived from an eccentric, the complete motion for the two valves being thus obtained entirely from the two crossheads. Successful modifications have also been introduced by Messrs. Kitson, of Leeds, and other engineers.

203. Motion diagram of Joy's radial valve gear (working). Presented by David Joy, Esq., 1900. M.2658.

This gear, which was patented in 1879–80 by Mr. D. Joy, is both a reversing and a variable expansion gear, but no eccentrics are used, the motion of the valve being derived from the swing of the engine connecting-rod.

The valve rod is attached to the short end of a long lever, the other end of which is indirectly coupled to the engine connecting-rod. The fulcrum of this lever is fitted with a block sliding in a curved guide, and the engine is reversed or "linked-up" by altering the angle that this guide makes with the valve rod. The guide is shaped to a circular arc of a radius equal to the length of the valve rod, and the block, when the engine is running, works equally on both sides of the centre of this guide. As the crank-shaft rotates, any point on the connecting-rod has a nearly elliptical path, which would give an unequal distribution of the steam at the two ends of the cylinder if the long lever were directly attached to the connecting-rod. To avoid this objection the motion is obtained from a link, one end of which is attached to the connecting-rod and the other to a radius rod. A point in this link describes an oval path, which gives a symmetrical motion to the slide valve.

It is stated that, in mid-gear, steam is admitted into the cylinder to the extent of the lead at each end, and that the lead is constant for all positions, while unequal lead can be arranged for, if preferred. A valuable feature of this gear is that it readily brings the valve chest into a position at right angles to that usually occupied.

For the sliding block and a curved guide, a swinging lever is sometimes substituted, the inclination of the curved path so obtained being altered by changing the position of the stationary end of the lever. Photographs of several varieties of engines so fitted will be found in the collection.

204. Model of Morton's valve gear (working). (Scale 1 : 4.) Lent by Morton's Valve Gear Co., 1889. M.2670.

This is a model of Mr. Morton's valve gear as fitted to a vertical marine engine. It is a radial gear without eccentrics, and was patented in 1882.

A radius rod, nearly in a line with the valve rod, controls the free end of a lever, which receives a compound motion from the connecting-rod

and the crosshead. From a point in this lever a rod extends to a pin in a curved slot rigidly attached to the slide valve; the position of the pin in this slot determines whether the engine is in forward or backward gear, and the grade of expansion. The rod from which the valve is directly operated describes a nearly elliptical path, with the major axis horizontal, and so gives a very uniform steam distribution at both ends of the cylinder.

205. Model of valve gear. (Scale 1 : 4.) Presented by Harry Gray, Esq., 1897. M.2989.

This gear, patented by Mr. Gray in 1893, combines the link of the common reversing motion with the single eccentric of Hackworth's gear; it is stated to give great latitude in adjusting the various points of cut-off.

The eccentric is set opposite the crank, and has two straps and eccentric rods corresponding with forward and backward gear. These rods sway rocking levers to which the rods from the two ends of the link are attached. Although the link is a shifting one, it is found that the least variation in lead is obtained with the reversing link curved convex to the shaft.

206. Motion diagram of Joy's fluid-pressure reversing gear. Presented by David Joy, Esq., 1900. M.2658.

This shows the arrangement of valve gear patented by Mr. Joy in 1892, for altering the point of cut-off of an engine, or reversing it, by moving the eccentric sheave in a straight line from the position for forward gear to that for backward.

The eccentric is forced over by means of fluid pressure, acting upon rams formed on the crank-shaft and working in cylinders fixed within the eccentric sheave. The fluid is introduced to these cylinders through central holes drilled along the crank-shaft, and by pipes connected with the fluid distributing arrangement. This consists of two vertical cylinders with a common piston-rod, the upper cylinder being for steam, and the lower for oil or other fluid supplying the pressure. Steam is admitted to either end of the upper cylinder through a small slide valve worked by the hand lever, and there is also a slide valve in the oil cylinder. The steam admitted into the upper cylinder moves the piston in the oil cylinder, and so, by the fluid connection, moves the eccentric over to a corresponding extent. If the oil leaks or an eccentric ram leather gives way, the eccentric goes to full gear, forward or backward, according to the way that the engine is running, and remains there.

An adjacent photograph shows this gear as fitted to a locomotive, but with the parts opened out so as to render the construction visible.

207. Model of automatic expansion gear. Presented by D. Halpin, Esq., 1901. M.2513.

In this valve motion by Mr. Halpin, there is a single slide valve and two eccentrics; one eccentric gives a simple reciprocating motion that controls the exhaust, while the other rocks a bell-crank lever, which rocks another bell-crank lever connected with the slide valve in such a way that it gives a vibrating motion to the valve. The outer lips of

the valve have a curved outline, so that any alteration in the angular position alters the lap; to make the arrangement more compact, the curve is made in two portions. The point of cut-off is altered by moving the position of a link in a slot of the bell-crank lever, and this can be done automatically by a governor.

208. Sectional model of automatic expansion gear. (Scale 1 : 4.) Lent by Messrs. Holborow and Co., 1886. K.486.

This represents a horizontal engine fitted with the valve gear patented in 1885 by Mr. H. G. Holborow.

In the steam chest is a main slide valve, worked by a single eccentric, and on its back is a gridiron cut-off plate worked by another eccentric; the motion of this cut-off valve is controlled by a Porter governor, in such a way that the proportion of the stroke done under full steam is decreased upon there being any increase in the speed of the engine. The expansion eccentric rocks a link, one end of which is carried by a pin moving with the main valve, and the cut-off valve rod has also a slotted link; into these two slots passes a block connected with the governor, which, by altering the position of the block, determines the amount of relative motion which the back plate receives from its eccentric, and thus determines the point of cut-off; the opening and closing of the exhaust port, being done by the main slide valve, remain unaltered.

209. Photograph of engine with Corliss valve gear. Lent by Messrs. Hick, Hargreaves and Co., 1888. M.1898.

The engine represented is of the tandem two-stage expansion type, with cylinders 32 and 54 in. diam. by 6 ft. stroke; under steam at 85 lbs. pressure, it makes 51 revs. per min. and indicates 1,200 H.P.

It is fitted with a modification, patented by Mr. W. Inglis in 1863, of the Corliss valve gear originally brought out in 1848. The valves are operated by "wrist plates" rocked by eccentrics on a countershaft connected with the crank-shaft, but the closing of the steam valves is effected, when released or tripped, by helical springs in small air dash-pots. The period of release is determined by a high-speed governor, assisted by a supplementary one patente l by Mr. W. Knowles in 1883, its function being to vary the length of the rod from the main governor to the trip gear, and so remove the slight change of speed that had caused the main governor to alter its height.

210. Motion diagram of locomotive valve gear with "Corliss" valves. (Scale 1 : 5.) Constructed by Mons. P. Regnard, 1899. M.3043.

This shows a valve gear introduced by M.M. Durant and Lencauchez, and considerably used on the Paris and Orleans Railway for both express and goods engines.

Each of the cylinders has two semi-rotating steam valves at the top, and two similar exhaust valves below. Such cylinders have been fitted to existing engines, the original valve motions, which were of the Gooch type, being retained. The two steam valves are worked by a rod from the block in the usual way, while the exhaust valves are driven from

another point in the block through an intermediate lever; linking up and reversal are performed by moving the block in the ordinary manner.

The large port areas, reduced clearance, and diminished "wall" surface secured by this arrangement were stated in 1893 to have shown a reduction of 15·2 per cent. in the steam consumption, when compared with that of similar engines with ordinary slide valves, and that the wear of the valve gear was still more materially reduced.

211. Motion diagram of the Wheelock valve gear. Made by Messrs. H. and T. C. Batchelor, 1889. M.2276.

The cylinder has separate steam and exhaust valves at both ends, all in the form of wide gridiron slides. The seats for these are formed on skeleton plugs secured into long, slightly conical holes, which are bored transversely to the cylinder. At the back of each slide is a short crank arm connected with the slide by a link, and these cranks are rocked from a single eccentric on the engine shaft. The steam admission valves each have their crank rocked by a latch lever connected with the external mechanism of the exhaust valve, but when the lever is lifted the valve is suddenly closed by a spring or weight checked by a dash-pot. The instant when the latch lever disengages is automatically determined by a cam lever controlled by the engine governor, so that any increase in the speed will cause the cut-off to take place earlier in the stroke. The introduction of the short cranks at the backs of the slides causes the exhaust valves to remain fully open for a longer time than would otherwise be the case, while with the steam valves considerable variation in the action of the dash-pots is possible without its causing any imperfect closing of the steam ports.

212. Diagram model of automatic expansion gear (working). Lent by Messrs. T. McCulloch and Sons, 1887. M.1858.

In this gear, designed by Dr. R. Proell, and patented in 1881, a double beat valve is used as an expansion valve. The opening is caused by an eccentric, through the medium of a rocking lever and bell-crank; the closing, when released, is done by a spring. The releasing is performed by a trip motion, the time of which is controlled by the position of the governor. In the model there are two bell-cranks, mounted on a rocking lever, which is oscillated by an eccentric. The vertical arms of the bell-cranks alternately, in their downward motion, lift the valve; the horizontal arms, by which the tripping is effected, are under the control of the governor.

213. Motion diagram of the Galloway and Beckwith automatic expansion gear. Made by Messrs. H. and T. C. Batchelor, 1889. M.2271.

This valve gear, patented in 1882–4, is intended for use in an engine having an independent exhaust valve and two steam valves driven by separate eccentrics. The diagram shows the eccentric and gear for one of the steam valves. The slide valve rod is moved a certain distance by the eccentric until a catch liberates the valve rod, when it shoots back to the closed position under the action of a spring or piston, a dash-pot being added to stop the valve quietly after the port has been covered.

The proportion of the piston stroke that is performed before the catch is liberated is determined by the engine governor. The motion from the eccentric is transmitted to the valve rod by a short horizontal lever, which, when slightly lowered, catches a projection on the valve rod. The lever has a roller connected with it rolling on a fixed incline, the amount that the roller is below the lever being determined by the speed of the governor, so that the distance rolled up the incline before the lever is lifted high enough to release the valve rod and so cut off the steam, is automatically controlled.

A photograph of an engine so fitted is also shown.

214. Motion diagram of the Willans central-valve engine (working). (Scale 1 : 2.) Made by Messrs. H. and T. C. Batchelor, 1889. (*See also* No. 94.) M.2273.

The engine has three vertical steam cylinders of increasing diameters placed tandem; the common piston-rod is hollow and of large diameter, and inside this rod travels the slide valve by which the steam is directed through the various cylinders. Each cylinder is single-acting only, the space between each piston and the top of the cylinder below forming a receiver. As the valve face travels with the piston the single eccentric which moves the slide valve is secured to the crank-pin, thereby giving the same relative motion as is usual with a fixed valve face. Immediately above the crank-shaft is a fourth cylinder, which forms a guide for the crosshead, which, in this case, is a long piston. This piston in the up-stroke compresses the air confined in its cylinder, and so maintains sufficient thrust on the connecting-rods, etc., to prevent any knocking through the rapid reversals of the motion of the pistons, etc. Owing to the unbalanced end pressure on the long piston valve the stress in the eccentric rod is never reversed. The crank and connecting-rods are lubricated at every revolution by their dipping into a bath of oil, contained in the lower portion of the crank chamber. High pressure steam is let into the upper dome or steam chest from which it passes by radial holes into the hollow piston-rod, down and out into the high-pressure cylinder. When the piston has descended some distance its supply of steam is cut off, owing to the upper ports through the rod becoming covered by the packing round it at the upper end of the cylinder. This steam expands till the down stroke is completed, and then, during the up-stroke, exhausts from the top of the first cylinder into the lower end, which forms a portion of the first receiver. In the second revolution this steam similarly passes through the second cylinder, and, after the third revolution, will have reached the lower side of the low-pressure piston, where it is discharged into the atmosphere or into a condenser.

215. Motion diagram of Holt's reversing gear. Lent by H. P. Holt, Esq., 1879. M.2512.

This auxiliary steam reversing gear was patented by Mr. Holt in 1876. The reversing piston has its motion controlled by a three-ported slide valve connected with the reversing lever, but also receiving motion from this piston. The ports of this valve are always open to the cylinder, but the passage of steam is prevented by a back cut-off valve of the short D type, without any lap. For each position of the control valve,

which is moved by a hand lever, there is a corresponding neutral position for the three-ported valve, and therefore of the piston and reversing lever, so that any motion of the small valve is followed by a corresponding movement of the reversing piston until steam is again cut off from both ends of the cylinder.

216. Joy's assistant cylinders for slide valves. Presented by David Joy, Esq., 1897 and 1900. M.3010.

These two examples, one of which has been sectioned, were fitted in 1889 to the engines of H.M. torpedo-boat destroyer "Speedwell"; they remained in use till 1900, and were then replaced by a later modification of the design.

The assistant cylinder was patented by Mr. Joy in 1886–7, for reducing the wear and frictional losses on the valve mechanism of large slide valves, by directly applying steam power to perform the greater portion of the work. It is placed above the steam chest, in the position usually occupied by the balance cylinder in vertical engines, and is provided with a piston attached to the rod of the main slide valve. On the side of the assistant cylinder is a small slide valve, of the piston type, which distributes high-pressure steam to the two ends of the assistant cylinder; this valve is moved by steam acting on one of its ends and admitted from the assistant cylinder when its piston, on approaching either extremity of its travel, exposes a small port communicating with one end of the valve. The travel, and consequent port opening, of the piston valve is controlled by adjustable end stops, while the ports of the assistant cylinder are connected by a plug valve, which forms a bye-pass should it be required to put this cylinder out of action.

By the action of this arrangement the momentum of the moving valve when nearing the end of its travel is at first being absorbed by cushioning assisted, finally, by live steam admitted through the piston slide valve; this steam then does the work of reversing and restarting the valve, the ordinary valve gear merely controlling the motion.

The adjacent sectional drawing shows a later and simplified form of the invention. In it the engine valve rod is provided with an elongated piston containing two side ports, which alternately coincide with a central port in the assistant cylinder when this piston is at either end of its travel; the piston in these positions also uncovers one of the two exhaust ports. If the valve in the diagram is imagined to be moving upward, the motion will at first close the upper exhaust port and compress the steam at the top of the cylinder, while when nearly at the top of its stroke boiler steam will be admitted from the steam belt, through the ports in the piston to the upper end of the cylinder; this charge of steam finally checks the motion of the valve and afterwards assists the downward travel until the upper exhaust port is again opened, and so on. The work is done chiefly by cushioning, so that the actual consumption of steam by the cylinder is small, while, by adjustments, the downward tendency due to the weight of the valve is corrected. This diagram shows also copies of indicator cards, taken from the two ends of the cylinder, which explains the small steam consumption involved.

GOVERNORS.

217. Model of cataract governor. Received 1883. K.363.

This shows the hydraulic governor used for "tripp'ng" the valve gear of a Cornish pumping engine, and by which the number of strokes per minute can be adjusted to the work to be done, owing to the alteration it peimits in the interval of rest at the completion of each double stroke. In many engines, however, there are two cataract governors, so that there is a period of rest at the end of each stroke during which the pump valves return to their seats.

The arrangement consists of a weighted plunger in a vertical cylinder arranged in a water cistern, from which, when the plunger is raised, water enters the cylinder through a non-return valve; upon the plunger being released it descends at a rate determined by the amount by which a valve at the side of the cylinder is opened. The plunger is raised by a lever moved by a tappet on the plug-rod of the engine valve gear, and the subsequent descent of the plunger lifts the catches, and so releases the valve that controls the next stroke of the eng:ne. A complete cataract valve gear is shown in action in the Cornish pumping engine No. 55?.

218. Experimental chronometric governor. Presented by John Hick, Esq., 1887. M.1839.

This is a very simple form of governor, patented by Mr. Benjamin Hick in 1840, for controlling the throttle valve of a steam engine, and depending for its operation upon the resistance offered by the air to the rotation of a fan. The boss of the fan is a nut working on a quick-threaded screw cut on a vertical spindle driven by the engine. The resistance of the air retards the fan, and its nut mounts the thread of the screw when the speed of the spindle increases. This motion partly closes the throttle valve.

219. Chronometric governor. Lent by J. Standfield, Esq., 1863. M.1771.

This governor, patented in 1861 by Mr. J. Standfield, involves the same principle of intermediate bevel-wheels as does that of Siemens, No. 222; and will be more readily understood by reference to the latter; in this case, however, there is also a dial for indicating varying speeds, and the resistance against the carrying round of the intermediate bevel-wheels and the consequent shutting of the throttle valve, is provided by an adjustable coiled spring.

The resistance to the rotation of the governor is provided by a dash-pot or revolving vessel containing water. This vessel is provided with internal vanes, which carry the water round, and dash it against other vanes, within the vessel but mounted on a vertical spindle, which is prevented from rotating by a spring balance with index and dial. When the speed is increased, the work done in agitating the water is increased, and the pressure exerted by it against the shaft vanes turns the vertical shaft through a portion of the revolution, at the same time indicating the speed on a scale on the dial.

220. **Engine governor. Lent by Messrs. Napier Bros., 1888.** **M.2260.**

This, which is known as the "cat" governor, works on the principle of Froude's dynamometer. It was patented in 1880 by Messrs. J. D. and R. D. Napier.

A wheel, shaped like a saucer, with internal curved paddles or vanes, revolves rapidly in a tank of water. A similar wheel, mounted on another spindle, faces the first. The vanes of the revolving wheel dash the water (with more or less violence, according to the speed) against those of the second wheel, giving the latter a tendency to rotate, and close the throttle valve; this tendency is resisted by a lever, weighted according to the speed required. A duplicate pair of wheels are placed beside the apparatus to show the construction.

221. Allen's governor. Lent by Messrs. Whitley Partners. 1892. M.2469.

By this governor the supply of steam is regulated by the frictional resistance of a paddle immersed in fluid, and driven by the engine.

It consists of a standard carrying a shaft, which is driven by a pulley and has a six-armed paddle-wheel keyed to it. The wheel is enclosed in a casing attached to a shaft on the same centre line as the driven shaft. The interior of the casing is provided with ribs, which just clear the paddles, and is partly filled with oil, so that by the rotation of the paddles the fluid exerts a considerable force, tending to rotate the casing by a kind of fluid coupling. The motion of the casing is, however, resisted by an adjustable weight hung by a chain from a suitable cam on its shaft, so that the action of the weight increases as the casing is carried round. On the shaft of the casing is a pinion gearing into a segment on the lever of the throttle valve, which is of the equilibrium piston type and contained in the base of the governor. A sectional drawing is also shown.

222. Steam engine governor. Contributed by Sir C. W. Siemens, 1860. M.147.

In this governor, patented in 1844–5 by Mr. J. Woods and Sir C. W. Siemens, the top horizontal bevel-wheel is driven by the engine, and drives the horizontal bevel-wheel below it (which is carried by a hollow vertical shaft), through the medium of the two intermediate vertical bevel-wheels. Hung from the hollow vertical shaft are two semi-circular weights, which revolve freely within the casing up to a certain speed, and beyond that speed fly out and rub against the casing. The extra power required to be transmitted through the intermediate wheels to overcome the friction causes them to be carried bodily a few degrees round about the vertical shaft; the weighted lever, which opposes their motion, being lifted, and acting upon the throttle valve, regulates the steam.

223. Model of engine governor. (Scale 1 : 8.) Presented by T. Silver, Esq., 1869. M.1183.

This form of throttle valve governor was patented by Mr. Silver in 1855–7. It has crossed arms with balls on the end of each, the action

of gravity being thereby neutralised, so that the governor can be used in any position, or at sea. When the balls fly outward under centrifugal action, they are resisted by a spring connected with the sleeve working the throttle valve.

224. High-speed governor (working). Lent by Messrs. Ormerod, Grierson and Co., 1887. M.1870.

This is a form of high-speed governor, designed by Mr. C. T. Porter about 1868, and very largely used for stationary engines.

The small balls on the elbow-joints of the levers fly out by centrifugal force, and lift the large central weight, the motion of which is communicated, by levers and rods, to the throttle valve. This and other forms of governors, running at high velocities, are more sensitive than the older form having large balls running at low speeds, examples of which are to be found on the beam engines of James Watt, Nos. 36, 37 and 44.

225. Spherical governor. Presented by Messrs. John Bourne and Co., 1872. M.1261.

This construction of governor was patented in 1870 by Mr. John Bourne. It consists of a thin hollow brass spheroid divided by axial cuts into a number of flexible bars or ribbons. When rotated at a high speed, the centrifugal action causes the spheroid to increase in transverse diameter and diminish in length. This change gives motion to a collar which is connected with the throttle valve; there is an axial screw fitted with a wing nut, by which the action of the governor can be varied.

226. Buss governor. Lent by Messrs. Schäffer and Budenberg, 1888. M.1954.

In this regulator, described by Mr. Edward Buss as a "rotating astatic pendulum," and patented by him in 1876–8, a hollow vertical spindle, driven from the engine, carries at its upper end a bracket having four arms directed downward. These serve as centres for two swinging frames, which replace the arms of the simple pendulum governor. Each frame consists of a horizontal portion, forming an axis, and on each side of this an arm carrying at its further end a ball or weight. The frames are connected by short links, with a sleeve capable of sliding on the spindle, and carrying with it a vertical rod connected with a throttle valve arranged below, and which controls the supply of steam to the engine. The centre of gravity of each revolving frame is near the large weight and rather below the horizontal axis. The arrangement gives a very short and therefore high speed conical pendulum, but one in which the height alters very slowly as the angle increases, so that, although sensitive, the equilibrium is stable. After opening to about 20 deg., the stability of the pendulum reverses, thus bringing into play the full power of the control when necessary. A small screw in each of the lower weights provides for adjustment by altering the positions of the centres of gravity of the revolving masses.

227. High-speed governor. Lent by Messrs. Schäffer and Budenberg, 1888. M.1954A.

In this governor a vertical spindle driven from the engine carries four pendulums connected with a sliding sleeve and a central conical weight, which, together with a helical spring, presses the sleeve downward. A rod is connected at one end with the sliding sleeve and at the lower end is jointed to a crank fixed to the spindle of a cylindrical valve. When the engine moves faster the balls exert greater centrifugal force, and fly outward, and the sleeve moves upward, lifting the conical central weight, and compressing the spring. This upward movement of the sleeve causes a closing of the valve, and so reduces the supply of steam to the engine.

228. Pickering's governor. Lent by Messrs. Joseph Evans and Sons, 1891. M.2392.

Three balls are employed, each fixed in the middle of a separate plate spring. The lower ends of these springs are attached to a collar formed on the driving pinion, which runs free on a fixed central tubular column. The upper ends of the springs are secured to a cap at the top of the column, the cap being free to revolve and to rise and fall, so that as the balls diverge under the centrifugal force the top cap is drawn down, carrying with it a central shaft which is connected with a throttle valve contained in the lower casting. A helical spring is arranged to act upon an arm connected with the central spindle, and by means of a worm and worm-wheel can be adjusted so as to alter the speed while running. The example shown is for a 1-in. steam pipe, and should make 300 revs. per min.

229. Lindley's steam engine governor. Lent by Messrs. Browett, Lindley and Co., 1890. M.2291.

In this governor, patented by Mr. H. Lindley in 1884, the usual balls are replaced by two hemispheres capable of swinging outward round two lower centres, but forming, when closed, one sphere. The centrifugal tendency of the two hemispheres is resisted by two helical springs acting directly while the spreading motion of the revolving masses is transmitted by upper links to a central spindle which passes downward to an equilibrium throttle valve placed in the steam pipe below. By means of a sliding block, which can be adjusted while the governor is running, the action of a third spring can be caused to increase or diminish the resistance to centrifugal force, thereby altering the speed of the engine.

230. Expansion governor. Made by Messrs. Schäffer and Budenberg, 1894. M.2563.

This governor regulates the speed by cutting off the steam at an earlier point in the stroke when the speed rises above the normal amount, so giving a higher grade of expansion as the power required from the engine diminishes. It is arranged for fitting to a simple engine with the ordinary slide valve, and so converts it into one with an automatic expansion gear.

The upper part consists of a Buss governor similar to No. 226, but below this, instead of a throttle valve, is a cylindrical gridiron valve. This valve is in the main steam pipe, as near the cylinder as possible, and is slightly oscillated by a trip gear rocked by the eccentric rod of the ordinary slide valve. The gear consists of a horizontal rocking shaft carrying two catches, which engage with a stop on the expansion valve spindle, but when free the valve is returned by springs to the closed position. The catches project upward as curved horns, while a nearly horizontal arm from the governor spindle obstructs the swing of these horns, and so releases the catches at a period of their swing dependent upon the position of the governor balls. A dash-pot is provided to steady the tripping arm.

231. Shaft governor. Lent by A. S. F. Robinson, Esq., 1904. M.3341.

In this arrangement of centrifugal governor directly secured to the engine shaft, the speed of the engine is regulated by its varying the point of cut-off to suit the load. It accomplishes this by altering the position of the eccentric on the shaft in such a way that the angular advance and travel of the valve are varied while the lead remains constant. It was patented in 1894–9 by Mr. Robinson.

The mechanism is enclosed in a hollow fly-wheel or pulley fixed to the engine shaft, while the eccentric sheave is carried on one side of a frame composed of a pair of guide plates, placed one on each side of the wheel and connected by four shouldered studs passing through slotted holes in the wheel faces. The studs are joined in pairs by two bridge pieces, which are each tied by two steel strips to opposite lugs on the inside of the wheel rim. The eccentric frame and strips form a "Watt" parallel motion, constraining the eccentric to move approximately in a straight line at right angles to the crank, so as to maintain a practically constant lead. This frame is held in position by a pair of laminated steel springs, curved outward round the boss and passing between the parallel motion strips, these springs are fixed at one end to adjustable supports attached to the wheel and at the other to one of the bridge pieces of the sliding frame. The springs are controlled by four swinging levers pivoted at the fly-wheel rim and coupled together in pairs by links and compensating levers; these act through links and rolling contact pieces which bear upon the inside of the curved part of the springs, so that when the levers fly outward the springs are pulled apart and the eccentric frame is moved towards the centre.

The speed of the engine is adjusted by moving the fixed ends of the laminated springs, which can be effected while the engine is in motion by means of a disc sliding along the shaft; this disc carries a projecting rack, which engages with a pinion attached to a right and left-handed screw passing through the ends of short levers upon which the springs are mounted.

232. Hartung's governor. Presented by Messrs. Hermann Hartung's Successors, 1905. M.3386.

This governor, which was patented by Herr Hartung in Germany in 1893, and is widely used on the Continent, is of the spring-loaded centrifugal type.

The weights are flat but shaped on the rim to suit an external cylindrical casing keyed to the vertical governor spindle. Each weight is supported on the double arm of a bell crank lever which has its fulcrum in the casing, whilst the other arm is attached by a link to the sliding collar. The weights in all positions thus deviate but slightly from one horizontal plane so that the disturbing effect of gravity is almost eliminated. The weights are loaded by helical springs placed in recesses bored in them and bearing against plugs screwed on a through bolt, thus allowing of adjustment within narrow limits. This link-work therefore remains unloaded; internal friction is consequently small, which makes the governor sensitive and reduces wear.

The governor is so nearly isochronous, that a wide range in the number of revolutions cannot be obtained by altering the tension of the springs. Weights, however, may be placed on the sliding collar or a spring-balance may be attached to the linkwork for this purpose; this, however, increases friction and diminishes sensitiveness.

The casing acts as a protection against dirt, etc., while the top is easily removable to gain access to the springs.

233. Porte-Manville electrically controlled regulator. Lent by Messrs. Woodhouse and Rawson, 1887. M.2219.

This piece of mechanism for controlling electrically the speed of engines or other motors was patented in 1884 by Messrs. A. E. Porte and E. Manville.

On a horizontal spindle are two ratchet wheels of equal diameter, but with their teeth cut oppositely. These wheels are secured to a bevel-wheel on the same axis, gearing with a bevel-wheel on a vertical shaft, which is connected with the steam throttle valve, a set of resistances, or other means for controlling the energy supplied to the motor. On the horizontal spindle is also a rocking frame carrying two opposite pawls which by springs are lifted clear of the ratchet wheels, but the frame is provided with two electro-magnets, each powerful enough when excited to pull the pawl above it into gear. The rocking frame is connected by an arm with some reciprocating part of the motor, so that when a pawl engages, the power brought upon the controlling gear may be very great if required. The actual regulation is determined by the apparatus that sends the current through one or other of the two coils as necessary, the appliance shown being a means for enforcing these corrections. To prevent over-winding, a block on the vertical shaft screws up and down, and breaks the circuit when in the extreme positions.

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234. Reducing valve. Lent by Messrs. W. H. Bailey and Co., 1888. M.1947.

In this reducing valve, by Mr. Greenhalgh, there is a spring for maintaining a uniform pressure lower than that of the source from which the steam is taken. If a greater pressure comes on the valve, the spring acts and allows the valve to partially close, and so shut off some of the steam. A sectional drawing shows the internal construction.

235. Reducing valve. Presented by Messrs. W. H. Bailey and Co., 1903. M.3293.

The arrangement of this appliance, for automatically reducing the pressure of steam or other fluid to some lower but constant pressure, was patented in 1896 by Mr. J. M. Foster.

The valve itself is of the double-beat equilibrium type, but, to overcome the difficulties arising from the variation in temperature of the stem connecting the two discs, the face of the upper one is nearly flat, while the lower one has a very acute bevel. Above the valve box, but cast with it, is a circular dish separated by a flexible metallic diaphragm from a similar dish above it which is open to the atmosphere, while the spindle of the valve extends upward and is attached to a cap in the centre of this diaphragm. Above the top dish two horizontal tie-rods, connected by crossheads, control two helical springs under compression, and these, by short vertical levers, press upon a pair of toggle plates, which thereby exert a downward thrust upon the diaphragm and valve spindle.

The boiler steam enters the space between the two valves, and rushes to the reduced pressure pipe beyond; some, however, passes through a vertical communicating orifice to the under side of the diaphragm, which is thereby thrust upward, and carrying the valve with it reduces the supply of steam, and consequently lowers the pressure below the diaphragm. In this way the valve finds and maintains a position in which the pressure of the reduced steam on the diaphragm balances the effort exerted by the external helical springs. By the introduction of the toggle plates the rise in the reduced pressure, which would result from the increased compression of the springs when the valve is fully opened, is prevented by the alteration that at the same time takes place in the angle of the toggle joint.

Lubricators.

236. Suet lubricator. Lent by Messrs. Nettlefolds, Limited, 1888. M.1944.

This is a cup lubricator, designed for using suet or other grease requiring heat to liquefy it, as sometimes supplied to steam cylinders or large bearings; it was patented in 1866 by Mr. J. Storer. The cover for filling is secured by a bayonet joint, made steam-tight by having a sharp edge, which is forced down on a soft metal seating by an external screw. Internally there is a cylindrical strainer, to keep back solid matter and prevent choking of the outlet pipe. The rate of feed is regulated by a cock.

237. Grease lubricator. Lent by Messrs. Trier Brothers, 1888. M.1895.

This fitting, for supplying solid lubricants to bearings, was patented in 1878, by Mr. B. Stauffer.

The cup for containing the lubricant (a sample of which is shown in a glass jar) is screwed internally to fit a disc formed with the nipple screwing into the bearing. Upon slightly turning this cup, or cap,

some of the grease is forced into the bearing and in this way the lubricant is supplied at intervals while its viscosity prevents its flowing away. In a later form which is shown in section, there is a small spring-loaded piston on the cap, which gives a continuous supply and indicates when the cap requires to be screwed further home; the rate of feed is adjustable by an internal set-screw which contracts the delivery passage.

238. Sight feed lubricator. Lent by Messrs. Sidney Moorhouse and Co., 1888. M.1892.

This is an apparatus for automatically feeding drops of oil into the steam-pipe of an engine, for lubricating the slide-valve and piston, the rate of feeding in the drops being regular, and, for the sake of thorough control, visible to the eye.

Water condensed in the upper vessel and partly filling the vertical pipe exerts a pressure on the oil in the reservoir, which is thus forced through the outlet-pipe and fine orifice of the conical nozzle within the glass tube; the drops float up through the water in the glass tube, thus being visible, and pass to the engine steam-pipe.

239. Sight-feed lubricator. Lent by Messrs. John Smith and Co., 1896. M.2929.

This is a modified form of feed lubricator patented by Mr. A. D. Ottewell in 1895. Like others of its class, it introduces oil in small quantities into the steam entering the cylinders, and so lubricates the internal working parts, while through a short glass tube each drop of oil supplied is visible, so that the correct rate of feed can be secured by adjustment, and the action of the lubricator can be inspected.

The apparatus consists of a large chamber containing the oil, and a smaller chamber above in which steam is regularly condensing. The steam condensed passes through an internal pipe to the bottom of the oil reservoir, displacing oil which escapes through a nozzle in the top of the reservoir into a short glass tube which is filled with water from the condensed steam; through this water the oil ascends in drops at a rate that is controlled by a valve at the side of the reservoir. The condensing chamber has a side passage controlled by a valve, through which the steam enters and also the oil escapes, the water-level in the chamber standing at the level of this outlet, so that any excess of condensed water will flow out into the steam-pipe, as will also the oil that, having risen through the glass tube, is floating on the surface of this water. When all the oil has been used, and the lower reservoir is accordingly full of water, the valves are closed and the water run out through a drain-cock at the bottom of the reservoir, while a fresh supply of oil is introduced through the filling-plug at the top of the reservoir. A sectional drawing of the apparatus is shown.

240. Sight-feed lubricator. Presented by Messrs. Walter Lees and Co., 1903. M.3300.

This is a sectioned example of the mechanical lubricator patented in 1893 by Mr. T. W. Lees by which the oil required is forced into the cylinder or bearing at a visible and adjustable rate by a small pump driven by the machine.

The apparatus consists of an oil reservoir from which, by an adjustable side orifice, the oil passes, in drops within a vertical glass tube, to a passage leading into a small ram pump. The ram extends upward into the reservoir, where there is an eccentric on a shaft slowly rotated by an external ratchet wheel, driven by a pawl on an adjustable lever rocked by the engine or shafting. The delivery-valve of the pump is spring-loaded and serves also as a check-valve, but a suction-valve is dispensed with, as the plunger is arranged to overshoot, and thereby close the orifice admitting the oil into the barrel.

During the up-stroke the accumulated drops of oil sucked from the reservoir pass into the pump, to be forced out through the check-valve during the completion of the down-stroke.

241. Self-acting lubricator. Received 1907. M.3496.

This is an example of a positively driven lubricator patented in France by Mons. A. M. Mollerup in 1881. It is employed extensively on the Continent for the lubrication of cylinders of large engines, and a modified form is now manufactured and used in this country.

It consists of a lower vessel to contain oil, fitted with a hollow plunger or piston, which is actuated by an arrangement of ratchet, worm and screw gearing. The upper end of the piston forms a nut for a square threaded screw which has a loose worm-wheel on its upper end. This wheel gears with a worm driven by a ratchet-wheel, the long ratchet arm obtaining its motion by its attachment to a reciprocating part of the engine. Thus at every stroke of the steam engine a slight turn is imparted to the square threaded screw, and this, being fixed in position, causes the nut, *i.e.*, the piston, to descend and force out oil into the distributing pipe, which is attached to the upper part of the oil cylinder. The rate of oil feed can be adjusted to suit the requirements by moving a sliding block on the ratchet arm, and thus varying the motion given to the ratchet wheel at each stroke of the engine.

When a wing nut above the plunger screw is tightened the worm-wheel and the screw rotate as one, but when this nut is loose, the worm-wheel revolves freely on the screw and the plunger can be raised or lowered by turning the handle at the top of the lubricator.

To fill the lubricator, the wing nut is slackened, and the plunger is drawn to the top of its stroke. Oil can then be poured into the lower vessel through the cup at the side.

The plunger is only allowed to rise and fall; its rotation is prevented by a piece of bent wire, U shaped, at its upper end, which is guided by a vertical fixed wire rod. The screw is only just long enough to allow the plunger to reach its lowest position and empty the vessel of oil; any further rotation then winds the screw out of the plunger. This prevents the machine being subjected to strains.

Packing.

242. Metallic piston packing. Presented by Messrs. Mather and Platt, 1858. M.293–5.

This form of packing was patented by Messrs. W. and C. Mather in 1846. It consists of an external cast-iron ring flanged internally at

the ends, and converted into a band by a helical cut, which goes twice round the ring, but terminates abruptly at each end. To prevent the passage of steam through the helical cut, a metal cover piece is fitted to the ring on each side. To expand this ring both radially and endwise, a helical spring constructed somewhat like the external ring, but of smaller diameter, is prepared, and inserted within the true ring. A wooden model of a piston fitted with this packing is shown, together with the internal and external portions of the packing for a larger piston of this kind. The packing is inserted by providing the piston with a junk ring held down by set screws, and an enclosing band tightened by a set screw has been provided for compressing the spring when the piston is being entered into the cylinder.

243. Piston with metallic packing. Presented by B. Goodfellow, Esq., 1857. M.139.

This packing was patented in 1838 by Mr. Goodfellow. The two packing rings are bored conically internally, to correspond with an internal spring ring which has conical surfaces. The spring ring is turned somewhat eccentric, and is cut through, and, to give greater uniformity of action throughout its circumference, several deep radial notches are cut in its periphery.

244. Metallic piston packing. Lent by Messrs. Lockwood and Carlisle, 1887. M.1862.

This construction of packing was patented in 1881–4 by Mr. W. Lockwood. There are two split rings, bored slightly conical, and inside them are two sets of wire springs, one giving radial pressure and the other end pressure. The radial pressure is exerted by flattened helical springs, made of round wire, and the end pressure by gridiron springs placed between them. The different springs are combined alternately into a complete circle.

245. Metallic piston packing. Lent by Messrs. Lancaster and Tonge, 1887. M.1879.

This construction of packing was patented in 1884 by Mr. H. Lancaster. There are two split piston rings, each formed with an internal end flange, and between these flanges is a helical spring of round wire, bent to fit the circumference, and butt jointed. This internal spring exerts upon the rings both the radial and longitudinal pressures desired.

246. Piston with metallic packing. Lent by Messrs. T. Bates and Co., 1888. M.1899.

In this packing there are two split piston rings of L section, expanded radially, and separated longitudinally by about three turns of a single helical spring. The method of construction of this internal spring was patented in 1874 by Messrs. Wigzell, Pollit and Mellor, and consists in tapering a bar of spring steel to the required shape, winding it on a revolving mandrel, and tempering it in oil. A larger example of this spring is also shown, together with the clamp used to hold the rings while getting the piston into the cylinder.

247. Metallic piston packing. Lent by Messrs. W. Buckley and Co., 1891. M.2363.

This packing was patented in 1878 by Mr. W. Buckley. It consists of two equal steel rings, bored conically inside, and cut through at one spot, gun-metal cover pieces being fitted to prevent leakage between the ends of the rings. Between these rings is placed an internal ring, formed by coiling wire of rectangular section into a helix, flattening it, and joining the ends, after it has been bent to a circle, by a flat core. This ring, pressing on the inclined interior surfaces of the split rings, expands them radially, and also forces them apart longitudinally, so as to maintain a tight joint on the sides of the recess in the piston, as well as on the cylinder.

248. Rowan's piston packing. Lent by J. Hind, Esq., jun., 1891. M.2418.

In this packing the radial pressure expanding the rings, and that securing the tightness of the rings against the sides of the recess in the piston, are obtained by independent springs.

Two rings cut and fitted with the usual joint cover-piece are employed, the radial expansion being secured by a short and flattened helical spring acting between two abutments provided inside the rings on each side of the cut. The longitudinal pressure, forcing the rings tightly against the sides of the piston recess, is supplied by inserting between the two rings a "wave spring," formed by bending a flat bar of steel into a circle and then corrugating it. On screwing down the piston junk ring, these corrugations, or waves, are flattened to the extent necessary to give the requisite pressure. It is stated that a radial pressure of about ·8 lbs. per sq. in. is sufficient to prevent steam passing between the ring and the cylinder, but that a high longitudinal pressure is required to maintain the rings tight against their recess, depending upon the piston speed and the steam pressure.

249. Faull's metallic piston rod packing. Lent by E. M. B. Faull, Esq., 1879. M.2510.

A small example of this packing, patented by Mr. E. M. B. Faull in 1878, is shown as fitted to a piston rod 1 in. diam. The packing is arranged to occupy the usual stuffing-box and to be tightened by the gland. It consists of a gun-metal ring with conical ends, divided by zig-zag cuts into three segments. The segments are held by a brass ring at each end, which, being conically recessed, press the segments on to the rod when closed together by the gland. One turn of gasket packing is placed at the gland end to hold the lubricant.

250. Metallic piston rod packing. Lent by Messrs. Mather and Platt, 1893. M.2531.

This packing is so designed that it may be placed in stuffing-boxes of ordinary construction, and be used to replace the fibrous packings so generally employed for piston and valve rods. It consists of a split cast-iron casing, turned to freely fit the stuffing-box, and provided internally with four deep grooves. In each groove are fitted two white

metal rings cut through and breaking joint, the requisite elasticity for closing-in being given by an encircling steel spring. In cases where packing cannot be slipped over the piston rod the white metal rings are formed in halves with overlapping joints, and the closing steel rings are also in halves, but dovetailed together. Rings for both arrangements are shown. The packing is held in place by the ordinary gland, an india-rubber washer being added at each end to give flexibility.

251. Sectional model of Duval's metallic packing. Presented by J. B. Von der Heyde, Esq., 1901. M.3176.

This shows a stuffing-box and gland, for a piston rod 1·375 in. diam., packed with the metallic gasket patented in 1886 by Mons. A. P. Duval.

The packing is formed of brass wire, of No. 36 I.W.G., plaited into a square coil, from which lengths sufficient to form separate rings are cut and placed in the stuffing-box so that they break joint. The metallic gasket possesses considerable flexibility and is incombustible, while its interstices retain the lubricant; it is made in various sizes from ·25 to 2 in. square.

252. Piston rod packing. Presented by the United States Metallic Packing Co., 1902. M.3247.

This packing was patented in 1893 by Messrs. W. E. Plummer and W. M. Kermode, and is a development of a form invented by Mr. E. Monroe in 1875. Its features are that it permits of free lateral and angular motion of the rod due to vibration, it is self-adjusting under wear, and its contact round the rod is chiefly derived from the steam pressure.

In the arrangement shown by the sectioned specimen the packing is of the duplex type, consisting of two separate sets of packing, the inner series partially resisting the steam pressure and the outer one completing the work.

The inner packing consists of three babbitt metal rings contained in a conical cup fitted with a gland which is forced home by springs assisted by the steam pressure. The front of the cup is free to slide on the plane face of a washer, the other face of which beds in a spherical recess on the stuffing box cover, while the gland end is free to slide on the plane face of another washer which is forced home by a number of helical springs, but the chief closing pressure upon the gland is that exerted by the steam. With the exception of the soft metal rings, the whole of these parts are bored much larger than the piston rod diameter.

The outer packing is similarly held endwise between flat and spherical faces kept in contact by springs assisted by the steam pressure, and so arranged as to give freedom for lateral and angular movement of the rod and its packing. The packing itself is, however, quite different, consisting of two rings each made up of gun-metal blocks and two blocks of babbitt metal, all forced inward by radial springs. The soft metal sectors break joint and also press upon the rod, while the gun-metal ones are quite clear of the rod; the reduced steam, moreover, which has passed the inner packing exerts a radial pressure upon these blocks which keeps them in closer contact with each other, and also presses the soft metal blocks upon the rod. Each babbitt metal block embraces

one-third of the circumference of the rod, and as the four blocks break joint the complete circumference is thus fully covered.

It is claimed that, owing to the closing of the packing being automatically performed by the steam pressure, the arrangement works for many years without attention, and that wear is diminished owing to the pressure being relieved during the exhaust strokes.

253. Cylinder drain and relief valve. Lent by H. P. Holt, Esq., 1879. M.2518.

This arrangement of valve, patented by Mr. Holt in 1878, combines in one fitting the drainage and relief safety valves for both ends of an engine cylinder.

Pipes from the two ends enter the casing shown, and the discharged water from the cylinder is carried off by a central pipe. In the casing is a valve for each end of the cylinder, and each of these valves consists of a central disc or relief valve, and also of a double-seated annular valve outside, which is the drain valve; these annular valves are kept on their seats by springs. The action is such that, when steam is on one side of the cylinder, its pressure opens the drain valve of the other end or exhaust side, while, at any time, the central or relief portion of the valve will open should the pressure, through priming, exceed the limit determined by the springs.

254. Steam quieting chamber. Lent by G. Beck, Esq., 1879. M.2509.

This apparatus for reducing the noise of the exhaust from a high-pressure steam engine was patented by Mr. T. Shaw in 1875, but it has been much more extensively applied to gas engines.

It consists of a cylindrical chamber arranged vertically, and provided with grids near the upper and lower ends. From the grid to the top of the chamber the space is filled with glass beads, marbles, or pebbles, so that the discharged steam, delivered into the space below the grid, in passing up through the small interstices is hampered, and the sharpness of its exhaust reduced.

255. Specimens of Clarkson's atmospheric condenser. Presented by the Clarkson and Capel Steam Car Syndicate, 1901. M.3171.

This construction of air-cooled condenser was patented in 1895 by Mr. T. Clarkson, and has been extensively adopted for condensing the steam or cooling the water used in motor cars, owing to the large amount of cooling surface it presents to the air in proportion to the weight of the apparatus.

The fluid to be cooled is passed through a central tube of thin copper, the specimens shown being ·25 and ·5 in. bore respectively, and the exterior of the tube has rolled into it a helical depression into which is wound a continuous helical spring, whose coils slightly interlock and are held into their bed by an internal wire wound with it. The whole tube, with its added radiating surface, is then dipped in molten tin, by which complete metallic contact is made between the tube and the wires, while increased rigidity is conferred by the connection which the tin establishes between the successive coils at their points of contact. The

small diameter of the radiating wire gives great surface in proportion to its weight, while the high conductivity of the copper, together with the metallic connection, insures that the heat is conveyed to the wire loops as fast as the large amount of freely exposed surface disperses it to the passing air.

256. Radiator tubes. Presented by the Lune Valley Engineering Co., 1907. M.3476.

These are specimens of radiator or condenser tubes in which the cooling surface is increased by surrounding the tubes with wire coils constructed in the manner patented by Messrs. J. G. A. Kitchen and L. P. Perkins in 1903.

The thin copper tubes used are covered with a triangular helically formed coil of phosphor-bronze or aluminium wire, the ends of which are secured by soldered copper caps. The coil is formed by winding the wire closely upon a straight rectangular mandrel with rounded edges: this coil, when removed from the mandrel, partly unwinds and assumes a triangular form with the angles of each turn advancing upon those of the adjacent one. The internal diameter of the coil is somewhat less than the diameter of the tube, so that when slightly twisted it may be easily slipped on, and when released it securely grips the tube. It is claimed that no soldering or binding is necessary.

257. Model of McCarter's condenser. (Scale 1 : 6.) Lent by J. Wood, Esq., 1876. M.2508.

This form of condenser was patented in 1869–73 by Mr. J. W. McCarter, and is intended to dispense with the usual air-pump. It consists of a vertical cylinder that acts as an ordinary jet condenser. Below the condenser is a closed vessel into which the condensed water flows through a foot valve, and from which it is discharged by a delivery valve. Steam is admitted to this closed chamber by a valve driven by tappets on a rotating shaft above, so as to give six short admissions of steam per minute. At the same time that the steam valve is opened a similar delivery valve is opened, the air and condensed water being thus blown out by the steam. The arrangement is equivalent to using Savery's engine or a pulsometer in the place of the ordinary air pump.

258. Aero-condenser. Lent by Mons. F. Fouché, 1907. M.3471.

This is a condensing apparatus of the form patented by Mons. F. Fouché in 1880–1905, in which steam is condensed by passing it through passages of special form around which an opposite current of air is induced by a fan. It may also be used to heat air by means of exhaust or live steam for drying or ventilating purposes.

The apparatus consists of a rectangular sheet-iron chamber, at one end of which is fitted a fan driven by an electric motor. Within the chamber are placed vertically a number of hollow plates, each consisting of two thin metal sheets fastened together at the edges, a short distance apart, thus forming narrow rectangular passages which expose a large surface to the air current. These plates are connected together, with the steam inlet at one end and with the outlet at the other end, the steam flowing in the opposite direction to the air. At the connection

each plate has a circular orifice surrounded by a concentric projection on one sheet and a corresponding depression on the other, and between the two sheets is inserted a perforated ring which supports the joints while allowing the steam to pass through the plates. Between each pair of plates suitably shaped distance rings are placed and closing washers over the holes in the outside members of the group ; the plates and rings are then drawn tightly together by bolts passing through the connecting holes, jointing material being introduced if necessary. The sheets forming the hollow plates are stayed at intervals by being stamped inward to meet and riveted together.

The small specimen shown will deliver 350 cubic ft. of air per min., with the fan running at 2,000 revs. per min.; it will condense 35 lbs. of steam per hour and raise the temperature of the air from 60 deg. F. to 124 deg. F. when working without a vacuum, or 22 lbs. of steam and an air temperature of 100 deg. F. when working with a vacuum.

259. Model of Edwards air pump (working). (Scale 1 : 4.) Made in the Museum from drawings supplied by Edwards Air Pump Syndicate, 1904. M.3358.

In this construction of air pump for a condensing steam engine, which was patented in 1894 by Mr. F. Edwards, there are neither foot nor bucket valves; a simplification which reduces the vertical height of the pump and increases the practicable working speed.

This pump is either attached to the side of the condenser and driven by rocking beams or is entirely separate from the engine and driven by an overhead crank-shaft combined with it. The lower opening into the casing communicates with the bottom of the condenser while the upper one leads to the hot-well; a side door near the top gives access to the delivery valves, and there is a safety valve to prevent any pressure accumulating when "blowing through," or if the condenser should become hot.

The cover of the casing has a gland for the pump rod, but the use of a second gland is avoided by prolonging the stuffing-box downward till it makes a joint with the internal cover carrying the delivery valves. The working pump barrel is a separate liner fixed to and supported by the casing.

The bucket of the pump is a complete piston which during its down-stroke is forming a vacuum above it, but when nearly at the bottom of its stroke, it passes over radial ports through the barrel, through which passages the water and air from the condenser rush into the vacuum above the piston; the piston at the same time acts as a displacer in removing the fluids accumulated below it to its upper side. In the following up-stroke these fluids are discharged through the delivery valves in the cover as the piston approaches the top of its stroke; the piston is not packed, except by the water upon it, and the clearance volume at the top of its stroke is small. The bottom of the piston is made conical to avoid shock when displacing the water beneath it, and, owing to the way this water is thrown on to the upper side of the piston and there entrapped, the arrangement will work even without valves. The valves are of the disc type and are water sealed, but they can be easily removed or replaced even when the pump is at work.

260. Air pump valves. Lent by the Metallic Valve Co., 1889. M.2268.

Mineral lubricating oil has a solvent action on indiarubber, and its introduction has led to the disuse of that material for air pump valves. For this purpose flexible metal clacks held at one edge by set screws were introduced in 1846 by Edward Humphrys. The tendency to breakage at the line of flexure is avoided by the use of the curved guard shown, which at the same time holds the clack along a diameter, as patented in 1878 by J. G. Kinghorn and W. J. Coe. The clack is of copper or phosphor bronze sheet, often elliptical in shape, and rests on a suitable grating.

In another form there are several thin discs of the same metal of decreasing diameters loose on a central stud and lifting against a flat guard. Usually each disc except the top one is perforated, the next one below on the grating acting as a seating for it. They close independently, so reducing shock.

261. Thomson's air-pump valves. Presented by Messrs. Steven and Struthers, 1899. M.3056.

These valves are annular, and resemble arches springing from the inner to the outer seatings ; a few radial ribs give additional strength. The arrangement forms a strong and light valve, with double passages if desired ; it has been chiefly used in engine air-pumps.

262. Drawing of an intermediate receiver. Lent by E. A. Cowper, Esq., 1887. M.1876.

This is a steam-jacketed vessel, commonly called "Cowper's hot-pot," for receiving the steam after it has been used and expanded in the high-pressure cylinder of a compound engine, and before it passes to the low-pressure cylinder ; then, when the cranks have moved 90 deg., the steam passes out to the low-pressure cylinder, and in doing so is obliged to pass outside a lining and in close contact with the hot steam-jacketed vessel, thus becoming somewhat warmed up ; it then is used and expanded in the low-pressure cylinder, thus allowing of a large amount of expansion and consequent economy. The cranks are placed at 90 deg., and the steam is cut off before half stroke in the low-pressure cylinder, so that a second charge of steam is not allowed to enter it in the middle of the stroke. The receiver was first introduced in 1857, and the internal lining was added in 1862.

BOILERS.

The early experimenters with steam used spherical boilers made of copper and heated by an open fire, but as their efforts attained a larger and more practical scale the importance of economising fuel led to the closing in of the grate, and the addition of external flues of brickwork, as then common in vessels used for heating fluids in breweries and for similar purposes. To increase further

the heating and flue surface, Savery in 1698, when working at pressures of 45 lbs. and probably higher, since he then used no safety valve, elongated the spherical shape and so introduced the cylindrical egg-ended boiler, which, arranged vertically or horizontally, has for 200 years been the most extensively used type of externally fired generator for steam of more than 30 lbs. pressure.

Savery's difficulties with his boiler, together with a few explosions, limited his pumping apparatus to such moderate heads that the introduction of Newcomen's engine in 1712, by which any head could be pumped against by the aid of steam of only atmospheric pressure, led to the general abandonment for many years of high-pressure steam, and heating surface became the sole requisite of a boiler. In this way the haystack type with its spiral external brick flue became general, until Watt, about 1785, by elongating it, introduced the wagon boiler with its nearly flat sides and bottom, which, with the addition of a few stays, remained in extensive use till about 1850.

The internal furnace flue was used as early as 1756, by Brindley in a boiler having its shell of stone with cemented joints, and Smeaton introduced a globular fire-box into the interior of a boiler of haystack form. Trevithick, who early saw the value of high-pressure steam, had by 1802 adopted internal furnace flues, and, by returning them within the cylindrical shells, constructed self-contained, or portable boilers, which he and his followers adopted in the earliest locomotives. The single-flued cylindrical boiler, internally fired, but with external flues in the brickwork setting, is probably chiefly due to Trevithick, and is still known as the "Cornish" boiler, while the very general "Lancashire" or double-flued boiler is a natural development from it, since it would be easier and more advantageous as larger boilers were demanded to increase the number rather than the size of the internal flues. With increase in pressure and dimensions these internal furnace flues gave trouble through collapsing, but this difficulty has been surmounted by the addition of cross tubes, strengthening rings or joints, or by the use of corrugated flues, so that such boilers are now working at nearly the highest pressure used, while for economy they remain unsurpassed.

The vertical boiler, so generally used for supplying small engines, was suggested in a patent obtained by Rumsey in 1788 and in its modern form by Neville in 1826. In recent years, however, much has been done to increase the efficiency of this, at one time, decidedly extravagant type of steam generator.

The fire-tube or multitubular boiler was brought to a practical success by the Stephensons in their "Rocket" of 1829, and with its water jacketed and well-stayed flat-sided fire box has ever since been characteristic of the railway locomotive. Owing also to its compactness and its great power in proportion to its total weight, this form of boiler is generally employed with portable or semi-portable engines, while the typical marine or Scotch boiler is a

combination of the leading features of the Cornish and locomotive types.

Flash boilers in which there is no store of boiling water, the steam being generated by pumping water on to red hot metal surfaces as required, were proposed by Payne in 1736, and in 1825 the arrangement was tried by Perkins with pressures up to 1,500 lbs., but the Serpollet boiler which was successfully applied to steam carriages in 1889 is the best known example of this type.

Water-tube boilers are, at the present time, fast replacing the fire-tube type for all purposes where the quick raising of steam and exceptional forcing are desired. They have immense advantages over the fire-tube boiler, among which may be mentioned the ease with which they can be adapted to withstand great pressures, their comparative immunity from serious accidents, and their great power in proportion to total weight and bulk.

Such boilers are, however, by no means new, as in 1776 Blakey constructed a boiler with inclined water-tubes, and in 1803 Woolf patented and successfully introduced a pipe boiler into Cornwall, while in 1825 Eve provided for complete circulation in such generators by the addition of large external downcomers. The introduction of steam carriages for common roads, between 1820–35, gave rise to the invention of several successful forms of pipe boiler, but these died out again, and the subject was for the time generally abandoned. The early water-tube boilers were introduced largely, on account of their safety, as very small damage could result from the explosion of any of their elements. Owing to the limited water capacity of the tubes, however, very careful attention has to be given to the feed supply.

Notwithstanding the great variation in the construction and proportions of boilers now in use, the difference in their efficiencies is comparatively slight. The weight of water evaporated from and at 100 deg. C. per pound of good coal in ordinary work is between 7 and 9 lbs., while the heat generated by such coal would be equal to an evaporative power of about 13 lbs., giving, therefore, a boiler efficieney of from 50 to 70 per cent.

263. Haystack boiler. (Scale 1 : 12.) Made in the Museum from particulars supplied by the Coalbrookdale Co., 1907. M.3502.

This type of boiler, which, together with its setting, was probably only an adaptation of existing practice with brewers' pans and spirit stills, was used throughout the 18th century for supplying steam to atmospheric engines. Under the name of the "balloon" boiler it survived in the Staffordshire district till late in the 19th century; the period represented by the model is about the middle of that century.

At first it was the practice to place the boiler vertically under the engine cylinder, but about 1760, as the power of engines was increasing, the demand for more steam was met by an increase in the number of the boilers, placed in contiguous settings, rather than in their size. The boiler was under fired and set in masonry or brickwork, so that

the hot gases made a complete circuit of the sides on their way to the chimney in a way known as a "wheel draught."

As the pressure used was practically only that of the atmosphere, the question of construction was subsidiary to that of heating surface; accordingly we find that the flange boiler, which was the type used with the earliest Newcomen engines, had the side flue formed by a horizontal flange uniting vertical sides to a domed top. Later a slight improvement was made by adopting conical or concave sides, hence the name "haystack." The bottom was at one time recessed so as to form a spiral flue as patented in 1748 by Thomas Stephens and Moses Hadley, but generally it was flat or concave. Internal stays were but rarely used, and instances of boilers up to 15 ft. diam. without them are recorded. The numerous explosions that have been traced to these defects in shape and construction, and the low ratio of heating surface to cubic contents possible, have led to the disuse of this type of boiler.

The material of which the boiler was made was at first copper, often with lead for the top; the corners appear to have been made by flanging the plates. On account of their durability and less cost, wrought iron plates produced by hammering seem to have been substituted as early as 1725; this improvement is credited to Stanier Parrot, of Coventry. Cast iron was also used; even in 1776 Smeaton preferred this material for his boilers. It was not till about 1790 that plates and other sections produced by rolling became generally available.

The feed water was introduced through a valve controlled by hand into a cistern on a vertical stand pipe by which a column of water of sufficient height to balance the pressure within was obtained. The water level was indicated by the position of a lever connected with a float inside. The blow-off pipe was usually stopped simply by a wooden plug.

The model represents a boiler 11 ft. high by 12 ft. diam. at the dome, decreasing to 10 ft. diam. at the bottom. The grate area is 25 sq. ft., the heating surface 235 sq. ft., the water space about 550 cub. ft., and the steam space 300 cub. ft. The pressure would not be more than 3 lbs. per sq. in.

264. Model of Wagon boiler. (Scale 1: 12.) Made in the Museum, 1901. Plate VI., No. 5. M.3174.

This type of stationary boiler succeeded the haystack form used with the Newcomen engine, and was a considerable improvement in that it possessed greater heating surface and grate area, while being easier of construction. It was introduced by James Watt about 1780–90, and remained in general use till about 1850, when the gradual increase that had taken place in boiler pressures led to its abandonment through the inherent weakness of its shape.

The boiler usually had a semi-cylindrical top with concave bottom and sides, and was set over the furnace, from which the gases, after passing along the bottom to the end, returned along one side flue, and then passed back again by the other side flue, following the course known as a "wheel draught." At a later period a nearly square central flue through the boiler was introduced, and the gases from the furnace, after passing under the bottom, returned through this

flue, dividing at the front, so that one half of the quantity passed along each of the side flues, thus originating what is known as a "split draught." The feed water was introduced by a vertical stand pipe, or "feed-head," of sufficient height to prevent water being blown out of it by the steam pressure. In this pipe was a float connected with a damper in the main flue, so that if the pressure fell the rate of combustion was automatically increased; the feed water was supplied to the head from a cistern provided with a valve controlled by a float within the boiler.

The boiler represented was of 20 nominal H.P. It was 13·8 ft. long, 6·8 ft. high, 5·33 ft. wide at the water line, and had a heating surface of 200 sq. ft., a grate area of 20 sq. ft., and ordinarily contained 300 cub. ft. of water, and had a steam space of 115 cub. ft. The pressure would be 5 lbs. per sq. in.

265. Trevithick boiler. Received 1881. Photograph of similar boiler with engine. Presented by F. W. Webb, Esq., 1890. Plate VI., No. 6. M.1514 and M.2357.

This is a form of the return flue boiler which, combined with a high-pressure engine, was patented by Trevithick and Vivian in 1802, and subsequently extensively used for locomotives as well as semi-portable engines.

The boiler shell is of cast iron 1 in. thick, 3·6 ft. diam., and 5·5 ft. long; the back end, which is dished, is cast with it, while the front of the shell has a flange to which the wrought iron front of the boiler is secured by bolts. To this front the two ends of the return, or horseshoe, flue are riveted; the larger leg of the flue is 18 in. diam., and holds the grate, the return portion being only 10 in. diam. The front of the boiler also has a manhole, but the system of construction rendered the whole interior readily accessible for scaling and repairs, owing to the ease with which the boiler front and furnace could be removed.

The steam generated passed into a cast iron steam dome, surmounted by a 2 in. lever-weighted safety valve, from which it was led by an external pipe to the valve chest of the steam cylinder, which is 9·5 in. diam. by about 36 in. stroke. The cylinder is arranged vertically, and is steam jacketed, being almost immersed in the boiler to which it is secured by an upper flange. The boiler steam, after passing through a stop valve of the plug type, is admitted alternately to the two ends of the cylinder by a four-way plug valve worked by a tappet motion.

The general arrangement of an engine and boiler of this type can be seen by the adjacent photograph, which shows a similar engine restored and completed. The crank-shaft extends below the boiler, and is driven by two return connecting rods from the crosshead.

266. Model of egg-ended boilers. (Scale 1 : 18.) Presented by Messrs. J. and J. W. Pease and Co., 1862. M.1410.

These were formerly part of the large model of the self-acting incline at Upleatham (*see* Catalogue, Part II.).

The type of boiler shown superseded the waggon boiler, when the increase in steam pressures rendered flat and badly stayed surfaces dangerous. It consists of a cylindrical shell with hemispherical ends, and is fixed over a grate formed in a brickwork setting, leaving flues for the passage of the flame and gases round the boiler on their way to the chimney.

267. Models of brick settings for boilers. (Scale 1 : 16.) Contributed by R. Bodmer, Esq., 1861. M.539–40.

The boilers are of the externally fired egg-ended type. One model shows a form of setting tested in some boiler trials made by Mr. J. Graham in 1858. The flame and gases from a grate, of 34 sq. ft. area and 14 in. below the boiler, pass along a semi-annular flame space, 6 in. deep, straight to the chimney. It was considered that this setting was 30 per cent. more efficient than a similar setting with a deep flue.

In the other model the gases pass, from the furnace, along the bottom of the boiler, then return by one side flue, and finally proceed to the chimney by an opposite side flue, following a "wheel draught" (*see* No. 264). Air, which has been heated while passing through brick flues formed in the surface walls, is delivered at the bridge to complete the combustion of the gases from the furnace; this device was practically tested with some success in 1810 by Mr. John Wakefield, and has since been frequently re-invented.

268. "Field" boiler tube. Presented by Messrs. Merryweather and Sons, 1903. M.3282.

This is an example of the double water-tube for steam boilers, patented in 1862, by Messrs. M. and R. M. Merryweather and E. Field. By them it was applied to the boilers of steam fire-engines, in which lightness and rapid steaming are of great importance, this being the first practical application of an internal tube within a heated one for separating the currents of hot and cold water; much larger tubes of the type have since been used in many forms and sizes of steam generators.

The arrangement consists of an inner and an outer tube—the outer one, which is closed through its lower end being welded into a hemispherical shape, has its upper end expanded into the tube plate so that its exterior is exposed to the fire or hot gases; the inner tube is open at both ends and its upper end is provided with an enlarged mouthpiece, which projects above the tube plate into the water space and has three external fins supporting it centrally within the outer tube.

The water between the two tubes, becoming heated and giving off steam, rapidly rises and is replaced by cold water which flows downward through the central tube; the enlarged mouthpiece acts as a deflector in reducing priming, and also facilitates the entry of water into the down tube. In the Niclausse boiler and other developments of the concentric tube arrangement, the rising and downcoming tubes open into separate chambers to avoid any interference between the ascending and descending currents.

269. Model of horizontal boiler on yielding supports. (Scale 1 : 16.) Lent by Jeremiah Head, Esq., 1876. M.1424.

By this method of supporting a long boiler, patented by Mr. Head in 1870, the ends may rise and fall by expansion without altering the position of the points of support, thus reducing the stresses that frequently cause seam-rips.

The boiler represented is of the long egg-ended type in an ordinary brick setting, such as is used in iron works. Pieces of T iron are riveted to the boiler and attached by suspension rods to weighted

levers, with their fulcrums carried on cast iron bridges, two intermediate bridges, however, carrying suspension rods fixed by nuts. The steam connections are fitted with double bends or U pipes. By a hand wheel on the model the boiler may be curved so as to show the action of these supports.

270. Model of Coleman's double boiler. (Scale 1 : 16.) Lent by Messrs. Coleman and Morton, 1879. M.2504.

This is an experimental model of a boiler patented by Mr. H. S. Coleman in 1876, consisting of two horizontal shells fixed vertically above each other and connected by seven large necks. By a long internal tube in each alternate neck, communication is made between the bottom of the upper shell and the lower portion of the lower one. When in action, the water heated in the lower vessel rises through the necks, while the cooler water circulates downward through the internal tubes. The steam generated forms in the upper portion of the top chamber, and then passes into a small separating vessel fixed at the top. Glass ends have been fitted by which the circulation of the water can be observed. The boiler is mounted in a metal setting provided with two side doors, through which the heating surfaces can be cleaned. Between two shells two horizontal plates are fitted, the lower one leaving a space at one end of the boiler and the other a space at the opposite end, thus forming flues through which the gases from the furnace below pass backward and forward and backward again before reaching the chimney.

271. Model of Cornish boiler and setting. (Scale 1 : 12.) Made in the Museum from information supplied by Livet's Boiler and Furnace Co., 1903. M.1739.

The boiler has a single furnace flue, and is carried in a setting provided with flues which give a "wheel draught" (*see* No. 264). The special arrangements illustrated by the model are, however, the construction of the furnace bars and the setting patented by Mr. F. Livet in 1878. The bars are made of wedge section about 12 in. deep, for the purpose of warming the air passing through them; while, to avoid breakage from unequal expansion, each bar is composed of a separate upper and lower portion. The boiler is supported on cast iron cradles built into a continuous mid-feather wall, there being thus only two external flues; the gases pass through these flues in succession, and the section of the flues increases as the chimney end is approached. The flues are made of exceptionally large dimensions, with the object of retaining the hot gases for a longer time than usual in proximity with the boiler shell; their size also reduces the chimney draught required, and facilitates cleaning and inspection.

272. Drawing of a Lancashire boiler. (Scale 1 : 24.) Lent by Messrs. D. Adamson and Co., 1874. M.2482.

This represents a pair of modern Lancashire boilers, each 7 ft. diam. and 24 ft. long, with two flues 33 in. diam. reduced to 28 in. at the further end. The whole of the fittings and arrangements of such boilers are clearly shown, including the automatic low-water alarm,

double dead-weighted safety-valve, internal distributing pipe for the feed-water, and perforated collecting pipe for taking the steam from the highest part of the boiler. The plant was put down at the Vienna Exhibition of 1873.

The furnace is formed in short lengths of welded tube with the ends flanged out by rolling; this construction, known as Adamson's flanged seam, greatly strengthens the flue against collapse, and permits of joining the lengths without exposing the rivet heads and thick portion of the joint to the flame. Eight cross tubes, for increasing the heating surface and circulation of both the water and the gases, are welded into the flue beyond the fire.

The drawing also shows the method of setting and the brickwork flues employed. The weight of the boiler is carried on two fire-brick ledges, and the flues throughout have a fire-brick lining. The gases, after traversing the two furnace flues, pass downward and along towards the front by a wide flue directly under the boiler, and at the front the current splits and returns along the two side flues in two streams, which unite again at the base of the chimney.

273. Model of a Galloway boiler and setting. (Scale 1 : 12.) Made by Messrs. Galloways, Ltd., 1894. Plate VII., No. 1. M.2577.

This represents in section a Lancashire boiler of the "Galloway" type. The actual boiler is 28 ft. long by 7 ft. diam., and is capable of evaporating 6,000 lbs. of water per hour, giving 300 H.P. with a good engine. Two furnaces 2·8 ft. diam. unite in one flattened tube 6 ft. wide and 2·75 ft. high, forming a combustion chamber. This chamber is the feature of the Galloway boiler, and to give the necessary resistance to the collapsing pressure, thirty-three Galloway water tubes are introduced, the shape of the chamber enabling tubes to be used in which the flanges are perpendicular to the length. To deflect the gases amongst the tubes, four water pockets are inserted in the sides of the chamber. The furnace flues are welded longitudinally and united transversely by the Adamson flanged joint (*see* No. 272). The shell is in rings, each of a single plate, lap-jointed and double riveted, and the ends are each of a single plate. The front end is secured to the shell by a welded angle ring and gussets, and the back end by flanging it over and by the use of gussets. A 4-in. dead-weight safety valve is fitted, and also a combined high-steam and low-water safety valve.

274. Drawing of vertical boiler. (Scale 1 : 4.) Presented by Messrs. A. Verey and Co., 1875. M.2913.

In this arrangement of boiler, patented in 1867 by Mr. T. Messenger, a certain amount of tube surface is introduced. From the inner sides of the fire-box project curved tubes reaching to the top, while in the central space is a baffle block to deflect the flame amongst them. A curtain of sheet iron is placed in the water space to increase the circulation, while "heat pegs" or studs projecting into the flame space are added, and these are stated to have a heating surface of equal value to that of the sides of the box.

275. Sectional model and drawing of Richardson's vertical boiler. (Scales 1 : 8 and 1 : 4.) Lent by Messrs. Robey and Co., 1874. M.2503.

This is a vertical boiler patented by Mr. J. Richardson in 1873, in which considerable tube surface is introduced. The shell of the fire-box is much larger than the grate, and from the space between them, nearly vertical tubes pass upward to the crown of the fire-box. These tubes connect with the water space at each end, so that a good circulation of water is secured. From the crown of the fire-box the hot gases pass through nearly vertical tubes to the top of the boiler, where by a chimney with a large conical base the used gases are collected and carried off. In this boiler, therefore, the two sets of tubes act in the reverse manner.

276. Model of Cochran's boiler. (Scale 1 : 2.) Lent by Messrs. Cochran and Co., 1881. M.2505.

This sectional model shows a form of vertical boiler patented in 1878 by Messrs. E. Crompton and J. T. Cochran, in which some features of the horizontal multitubular type are introduced.

The fire-box is of hemispherical form, so as to avoid flat surfaces which have to be stayed. From the fire-box the burning gases escape through a circular opening to a combustion chamber above, and from thence pass through a number of short horizontal tubes into the smoke-box on the opposite side, from which they escape into the chimney. It is found that these short tubes are much more efficient than their limited length and surface would suggest. The boiler is built of mild steel, and the model shows fully the details of the method of construction adopted. To prevent radiation of heat from the combustion chamber a fire-brick lining is fitted, and to facilitate cleaning the tubes the smoke-box is provided with hinged doors.

In the model the surfaces in contact with the water are coloured dark blue, and those with the hot gases red. A modified form of this boiler is shown in the Marine Engineering Section.

277. Models of multitubular vertical boilers. (Scales about 1 : 8 and 1 : 12.) Lent by Messrs. Clarke, Chapman and Co., 1903. M.3302.

The larger model shows an arrangement of boiler patented in 1898 by Mr. J. B. Furneaux. The shell is cylindrical with a closed segmental top, and the fire-box is a truncated cone surmounted by a vertical cylindrical combustion chamber having a dished top. The cone is crossed by a large inclined water-tube, while from one side of the combustion chamber 130 fire tubes, arranged in vertical rows, extend radially to the shell. The ends of some of the tubes are contracted by ferrules to ensure equal distribution of the gases, which pass through them to an external smoke-box carrying the funnel and provided with sliding doors to facilitate tube cleaning. Three small tubes, passing radially from the outside shell, admit warm air directly into the combustion chamber to prevent the discharge of smoke or unconsumed gases. The shell of the boiler is extended downward to form the sides of the ash pan ; the grate, however, is not shown.

The smaller model represents a modification of this arrangement patented in 1899 by Messrs. J. B. Furneaux and W. A. Woodison. The combustion chamber or flue-tube is divided halfway up by a horizontal diaphragm of fire-clay, so notched that it can be passed up from below and then rest on ferrules projecting from some of the tubes. In this way the hot gases are caused to pass through the lower rows of tubes to the smoke-box on the outside, whence they return through the upper rows to the flue and pass out by a central chimney. There are ninety-six of these tubes arranged in vertical rows, but the whole circumference is not occupied, two spaces being left for scaling purposes, and the smoke-box is formed in two portions.

278. Models of Blake's multitubular vertical boiler. (Scale 1 : 12.) Lent by Messrs. Richardsons, Westgarth and Co., 1901. M.3209.

This construction of vertical boiler embodies several arrangements patented by Mr. J. Blake between 1878–97. The shell is cylindrical, with a domed top containing the manhole; the fire-box is in the form of an oblique cone, fitting the shell at the bottom and inclining to the back where it is connected with the base of a cylindrical combustion chamber having a dished top. These forms avoid the use of stays and therefore facilitate cleaning. The combustion chamber is completely surrounded by water, and from its front seventy horizontal fire tubes extend radially to the shell which is bossed out, where necessary, to receive normally those tubes which would pierce it obliquely. The grate is fired through a short oval tube connecting the fire-box with the shell, while the smoke-box, which is attached to the shell higher up and carries the chimney base, is provided with hinged doors for use when cleaning the tubes.

A separate mid-length section of the boiler shows an alternative arrangement of the combustion chamber and tubes. The chamber has a domed top and cylindrical back, which is stayed to the shell; the tube plate is flat, as is also the corresponding portion of the shell plating, so that the fire tubes are of uniform length and parallel; there are seventy-seven of these tubes, of which fourteen are provided with nuts so that they serve as stay-tubes.

279. Portion of a collapsed flue of a boiler. Presented by Messrs. Fraser Bros., 1877. M.1734.

This is a portion of a boiler flue which has collapsed by the external pressure of steam, owing to its getting overheated, through the water being allowed to get too low. It will be observed that the flue was not strengthened, by stiffening rings, flanges, or other means which are now adopted in boiler construction to keep the flue in shape, while the simple riveted lap-joint employed precluded its being made truly circular. The metal of this flue is, however, exceedingly good, being of the best Yorkshire iron, and, although it softened and doubled up under the steam pressure when the water had for some time left the furnace crown, yet no evidence of fracture is visible in the plate.

280. Photographs of collapsed flues from a steam boiler. Presented by the Butterley Co., 1898. M.3033.

These two flues were removed from a cylindrical boiler, the shell of which is 7·5 ft. diam. by 30 ft. in length. The flues were 3 ft. inside

diam. by 12 ft. long, made in lengths which were strengthened by Adamson's ring and flanged joint.

The working pressure was 200 lbs. per sq. in., but through shortness of water both flues softened sufficiently to collapse as shown, without, however, fracturing or causing any explosion or other damage.

281. Models of corrugated flues. (Scale 1 : 12.) Lent by Samson Fox, Esq., 1879. M.2506.

These show the form of furnace flue patented by Mr. Samson Fox in 1877. The plain cylindrical furnace subjected to collapsing pressure soon showed its instability as pressures increased, and many devices were resorted to for the purpose of preventing their distortion and consequent collapse. Mr. Fox's invention has been very extensively adopted, and it is claimed that, in addition to the increased strength obtained, the flue will easily alter in length without requiring any separate expansion rings, and has also an increased heating surface.

These flues are made as plain cylinders, and then corrugated by rolling or by swageing, short cylindrical ends being left for making the necessary joints. The corrugations stiffen and strengthen the tube against collapse in the same way that a plate of metal used as a column would be strengthened if rolled with the Z section, so increasing the least moment of inertia. Galloway tubes corrugated longitudinally are also shown.

282. Corrugated fire-box. Lent by Messrs. R. Garrett and Sons, 1894. M.2724.

The fire-box end of a small horizontal multitubular boiler of the locomotive type is shown. The top of the external fire-box has been removed to render the internal box visible, and many details in boiler construction are also shown by this sectional example.

The feature of the fire-box, invented by Messrs. Garrett and Sons in 1876, is the means by which the usually flat roof is prevented from being crushed into the furnace by the pressure within the boiler. The flat sides of a rectangular fire-box are easily supported by screwed and riveted stays as shown, which directly resist the pressure and are in simple tension. The semi-circular top of the external fire-box is in a form that requires no stiffening, as the pressure is internal. The flat top of the internal fire-box is usually supported by longitudinal girders placed above it, to which the roof is bolted. Messrs. Garrett dispense with these roof stays entirely, by simply corrugating the crown-plate longitudinally, thus forming it into a girder of very considerable depth and one possessing the desired strength and stiffness. A slight curvature in a direction at right angles to the corrugations is also given, which further adds to the rigidity, and also prevents the accumulation of deposit. The crown plate was at first made with three corrugations, but in 1879 the double-corrugated furnace shown, which provides a deep water pocket in the hottest part of the furnace, was introduced. It is stated that the durability of the fire-box is greatly increased by the freedom of expansion given by this system of support.

The model shows also the modern method of constructing such boilers, in which the use of angle irons is obviated by accurately flanging over the plates while hot.

283. "Serve" boiler tubes. Presented by Messrs. John Brown and Co., Ltd., 1904. M.3357.

These boiler tubes, patented in 1885 by Mons. J. P. Serve, are provided with internal longitudinal ribs, or fins, which increase the surface for the absorption of heat from the furnace gases, while the external cylindrical surface of the tube suffices for the transmission of this heat to the water; the ribs also increase the rigidity of the tubes. Some experiments, with plain tubes and ribbed ones of the same diameter and length, gave an increase of 15 per cent. in the amount of water evaporated per lb. of coal in favour of the ribbed tubes; for locomotive boilers, in which they are extensively used in France, the small plain tubes have been replaced by about one half the number of "Serve" tubes of larger diameter, and it is stated that by their use a boiler may have its tubes considerably shortened, thus reducing weight, without diminishing its power or efficiency. It was also found that 1·2 sq. ft. of inner surface of ribbed tube were equivalent to 1 sq. ft. of inner surface of smaller plain tube, and that by the use of ribbed tubes the requisite surface could be provided in a locomotive boiler with fewer holes in the tube plates than would otherwise be necessary.

The specimens show different stages in the process of manufacture, which consists in preparing, by rolling, a flat plate of the required width and thickness, but having the necessary ribs projecting from its surface; this plate is then bent to cylindrical shape and a lap-welded joint formed, either by passing the tube, on a suitable mandrel, between welding rolls or under a power hammer. At each end of the tubes the ribs are cut away for some inches to allow of their being expanded into the tube plates in the usual manner.

The tubes are made of mild steel, and in sizes ranging, for land boilers, from 2·5 in. to 3 in. external diam., those for locomotives being usually 2·75 in. diam.; those shown are 2·5 in. diam., ·125 in. thick, and have seven ribs projecting ·5 in.

284. Model of boiler flue. (Scale 1 : 8.) Lent by the Premier Boiler Tubes, Ltd., 1905. M.3381.

This arrangement of water tubes for the internal flues of cylindrical or shell boilers was patented in 1901–3 by Mr. W. McG. Greaves.

About half the flue rings situated nearest the back end of the boiler have each a nest of solid drawn tubes 2 to 3 in. diam. placed vertically across the flue, leaving segmental spaces on either side; flats are pressed on the flue-tube to take these tubes which are expanded in place.

In a Lancashire boiler of ordinary proportions an increase of heating surface of about 70 per cent. over plain flues and about 20 per cent. over Galloway tubes is obtained. Increased evaporation and efficiency as compared with both the above flues are claimed.

285. Drawing of sectional steam boiler. (Scale 1 : 15; details 1 : 2.) Lent by J. Harrison, Esq., 1862. M.906.

This steam generator was patented in 1859 by Mr. Joseph Harrison of Philadelphia. It consists of a large number of communicating globular iron chambers, cast in sets of four; the ends of each set are machined so that tight joints can be made when several sets are held

together by internal tie-rods. In this way the cells are connected into slabs, while by suitable castings and tie-rods a number of these slabs are similarly united to form a complete boiler of the requisite surface. The slabs are arranged with a slope of 25 deg. in a brickwork chamber, the furnace being at the lower end and the steam pipe at the top, while suitable bridges distribute the gases between the nests of cells. About one-third of the cell capacity is used as steam space, and in it a certain degree of drying or superheating is effected.

Exceptional portability and adaptability were claimed for the arrangement, as well as great safety, owing to the smallness of the individual elements of which the generator is built up. The boiler has since been somewhat modified, and as now constructed is given a slope of 40 deg. with the horizontal. On trial it was found that one of these generators, when tested to 875 lbs. steam pressure, leaked considerably at the joints, but that it became tight again upon the pressure dropping to 450 lbs. In some forms of sectional tubulous boilers the use of internal tie-rods has given trouble owing to the expansion of the external tube being greater than that of the rod.

286. Model of water-tube boiler and superheater. (Scale 1 : 8.) Presented by Messrs. Babcock and Wilcox, Ltd., 1903. Plate VII., No. 2. M.2265.

This construction of water-tube steam generator was first introduced in America in 1867, and has since been continuously manufactured, while at the same time it has undergone considerable modification and development.

The boiler consists of groups of straight water-tubes arranged over the grate and inclining downward at 15 deg. to the back, into the chamber or flue beyond. The upper ends of these tubes open into special vertical tubes, or "headers," connected above with a horizontal drum in which the steam and water rising from the tubes separate; the space within the drum above the water level acts also as the chamber or dome from which the steam is drawn off. The lower ends of the inclined water-tubes are similarly connected above with the other end of the drum, while the lower ends of these rear headers are attached to a small transverse drum serving as a mud chamber. These down-coming tubes and headers allow water from the separating drum to descend to the lower ends of the tubes, to replace the water carried up as steam, or with it, thus maintaining a complete and rapid circulation; the solid impurities to a large extent accumulate in the mud-drum, by precipitation during the downward passage of the water through the rear headers.

The model represents a boiler having 49 inclined water-tubes, 4 in. diam. and 14 ft. long, made of wrought mild steel. They are expanded at each end into the vertical connecting boxes or headers, also of wrought mild steel, each containing one zizgag row of tubes to accommodate which the sides of the headers are sinuous. For cleaning purposes these headers are provided with handholes opposite each water-tube, the handhole covers being faced metal to metal, and secured by wrought steel clamps. The tops of the headers are attached to a butt-jointed, double-riveted horizontal steam and water drum, 4 ft. diam., by means of tubes also 4 in. diam., expanded into holes bored in pressed "saddle-pieces" riveted to the drum; the front tubes are short, but the rear

ones much larger on account of the inclination of the main tubes. The mud collector, which is at the lowest point of the boiler, is made of cast metal, or of wrought mild steel, and is connected with the rear headers by short expanded tubes.

The entire boiler, with the exception of the furnace, is suspended by wrought-iron slings from iron girders resting on wrought-iron columns, so that the boiler can expand or contract without any strain being thrown on the surrounding brickwork forming the sides of the furnace and flue. Two fire-brick baffle screens arranged between the tubes cause the hot gases from the furnace, under the influence of the chimney draught, to pass upward, then downward, then upward again before escaping into the chimney at the rear; this course, together with the zigzag arrangement of the tubes, insures a large amount of direct impact by the gases.

The damper for regulating the draught is placed in the rear wall, and the doors for cleaning the tubes and removing the soot are in the side brickwork, while the front is rendered accessible by two large iron doors which, together with the rest of the metal front, are carried on the columns of the casing. The boiler is fitted with the usual mountings, comprising main steam stop-valve, safety-valve, feed-valve, blow-off valve, water-gauges, and steam pressure-gauge.

The model represents a boiler containing about 900 sq. ft. of heating surface, which would be capable of evaporating from 3,000 to 3,500 lbs. of water per hour; such boilers can be constructed for any pressure not exceeding 500 lbs. per sq. in., about 200 lbs. being, however, the most usual load.

The model shows also the Babcock and Wilcox superheater as arranged in such a boiler, to heat the steam generated beyond the temperature of the boiler, and so reduce the losses in the steam-engine resulting from cylinder condensation. This superheater consists of 24 solid drawn steel tubes 1·5 in. diam. bent into U form, arranged horizontally, and expanded at their ends into two wrought steel boxes or "manifolds," provided opposite the tubes with inspection handholes. The steam from the boiler drum passes down from a collecting pipe into the upper manifold, then through the superheater tubes into the lower manifold, from each end of which it passes in its dried and heated condition, to two pipes leading to the stop-valve arranged above the drum.

To prevent injury to the superheater tubes when steam is being raised from the cold boiler, an arrangement is provided for filling them with water. This consists of a connection with the water space of the boiler drum and two cocks, by opening the larger of which the water is admitted to the superheater so as to completely fill it, but any steam formed whilst the superheater is flooded rises directly to the boiler drum. When steam has risen in the boiler to the working pressure and before opening the boiler to the steam main, the large cock is closed and the small one opened, so that the water flooding the superheater is drained away, a gauge-glass being provided to show that the draining is completed.

The chimney represented is 30 in. diam. by 60 ft. high, and is composed of wrought-iron plates ·2 in. thick, riveted together; it is secured to a bolted down cast-iron base and is stayed by steel wire guy-ropes.

287. Model of Niclausse boiler. (Scale 1 : 10.) Received 1902. M.3261.

In this class of water-tube boiler the heating surface is formed by tubes, closed at one end and opening at the other into square vertical water chambers, or "headers," while within each tube is a smaller one conveying cooler water from another chamber in the "header" to the closed end—each double tube acting similarly to the tubes patented and introduced by Mr. E. Field in 1862. The application of the internal circulating tube to the inclined tubes of boilers of the water-tube type was accomplished by M. Collet, who also introduced the double-chambered header ; for the attachment of the outer tubes he, however, employed long internal bolts, and these proved to be unsatisfactory. The practical success of the arrangement is, therefore, due to the work of M. M. Niclausse, who invented and patented, between 1891 and 1900, a form of joint for this purpose which has overcome the difficulties and led to the successful introduction of this system of construction, particularly for marine boilers.

The model shows, partly in section, a Niclausse boiler arranged for use on land and having a brick setting. The boiler consists of groups of slightly inclined tubes, closed at the back ends and connected at the front in double vertical rows of headers, which themselves open at the top into a collecting drum or chamber—each double row with its header forming an "element." Within each tube is a smaller one, opening into an outer portion of its header, which also communicates with the collecting drum, so that water from the drum may pass down the headers and through the central tubes to the end of the larger tubes, and then, together with the steam generated, return through the passage between the two tubes and up the headers again into the drum, without the two streams mixing or interfering. The water level is above the bottom of the drum, and a dividing plate separates the hotter water from the cooler portion, including the feed water. There is, however, no lower water chamber, so that this form of boiler cannot be completely emptied without removing the tubes.

The method of attaching the tubes to the headers consists in the employment of a special sleeve or "lantern," passing through the header and fitting it by means of coned surfaces, while the smaller end is screwed to receive the outer tube. The lantern of the inner tube screws into the outer lantern, and dogs outside the headers keep the conical surfaces in contact, little retaining pressure being, however, required owing to the areas nearly balancing. An attached drawing shows this tube joint in detail, and also a later form of greater simplicity.

The boiler represented has a grate area of 45·7 sq. ft., and 1,420 sq. ft. of heating surface ; it would supply about 8,800 lbs. of steam per hour at a pressure of 256 lbs. per sq. in., which, in a suitable engine, would give about 440 H.P.

The marine type of this boiler is shown in the Marine Engineering Section.

288. Models of Stirling boiler. (Scale 1 : 12.) Lent by the Stirling Boiler Co., Ltd., 1903. Plate VII., No. 3. M.3272.

This type of water-tube boiler was patented in 1889 by Mr. A. Stirling, and the examples show a complete boiler and one in section, both arranged for use on land.

The boiler consists of a number of groups of steeply-inclined tubes, expanded at their upper ends into three cylindrical steam and water chambers, and at their lower ends into two cylindrical mud drums, in which the water, being comparatively quiet, deposits its sediment.

The feed water is admitted to the upper chamber farthest removed from the fire, and this chamber contains the automatic float for regulating the water level. The tubes leading thence to the mud drum serve as downcomers for the water passing to other sections of the boiler and, in heating the feed water, act somewhat like those of an economiser.

The sides, roof, and fire-box of the boiler are of brickwork, but the weight of the boiler is carried, and the walls supported, by a steel framing. There is a brick arch above the furnace, which assists in directing the flames towards the tubes, and between the groups of tubes are baffles, formed of fireclay slabs, arranged so as to cause the hot gases to traverse the whole of the tube surface before reaching the chimney through the damper door at the back. Through the side wall there are protected openings which give access for the scraping tools used in cleaning the exterior of the tubes.

The steam generated is withdrawn from a steam dome fixed upon the central chamber, into which the steam from the wing chambers is led by curved horizontal pipes, an arrangement which, it is stated, conduces to dryness in the steam.

The complete boiler represented is of the middle size constructed, and has 56 sq. ft. of grate area, 2,900 sq. ft. of heating surface, and would supply about 12,000 lbs. of steam per hour at a pressure of 160 lbs., giving about 600 H.P. with a suitable engine.

289. Models of boiler explosions. Scales as shown. Presented by E. B. Marten, Esq., 1900. M.3132.

These models were made by Mr. W. Winship, and formed part of an extensive series commenced in 1862 by Mr. Marten, of the Midland Steam Boiler Insurance Co., to represent the features of the most important boiler explosions as they were investigated. Amongst them will be found some types of boiler and setting not otherwise represented in the Museum.

Each model is in duplicate, one showing the original state of the boiler and the other the portions of the boiler after the explosion; the two models are, however, placed close together, as considerations of space prevent the distribution of the fragments in the way that actually occurred, some pieces having been hurled more than 300 yds. from their original positions.

The flight of an exploded boiler is due to similar unbalanced forces to those in a rocket, the steam in the boiler and that given off by the water acting like the powder gases; in several of the instances shown, however, the boiler appears to have failed like a rocket case that breaks up as an explosive shell—an action that has not yet been fully explained. The destructive energy of a boiler depends upon the pressure and the amount of water in it, but the damage done by the explosion is largely influenced by the rapidity of the dissipation of the energy as determined by the area of the rent, so that if this is sufficiently restricted the result may be nothing more serious than a leakage of steam or water.

290. Model of Horsfall's refuse destructor. (Scale 1 : 12.) Lent by the Horsfall Destructor Co., 1901. M.3193.

This arrangement of furnace for the destruction of refuse was patented by Mr. W. Horsfall in 1887–98, and has been extensively adopted. Although such furnaces, when originally introduced in 1876, were only intended to dispose of the ash bin refuse of towns in an economical and inoffensive manner, it was subsequently discovered that the heat developed during the combustion could be utilized for the generation of steam in boilers arranged about the flues of the destructor; this steam has been very generally utilized in engines employed in electric lighting. The result of working in this way is that the refuse is reduced about two-thirds in weight, and to an inoffensive clinker which can be usefully employed, while the excess heat of the combustion generates in the attached boiler about one pound of steam for each pound of refuse consumed.

The furnace of the destructor shown in the model is a low arched chamber built in ganister brick and has more than half of its floor formed of furnace bars, the remaining portion serving as a dead plate. The refuse is introduced on to this dead plate, or desiccating hearth, by a charging door at the back, and the clinker is removed through a wide door at the front. After drying, the charge is burnt upon the bars and the gases all pass over the hottest part of the fire, then upward through a flue, near the clinkering door, into a large combustion chamber, and thence by a downcast flue into the main flue leading to a stack which serves for several of these furnaces or cells. The ash pit is closed and is supplied, by the action of a steam jet apparatus, with air under pressure by which the temperature of combustion is raised from 1,000 deg. F. to 1,500 deg., or even 2,000 deg. The sides of the hearth are formed of cast-iron boxes which have perforated removable sides, and are cooled by air passing through them on its way to the space below the furnace bars.

The structure is held together and strengthened by steel girders and tie bolts; the various flue-cleaning doors are carried by cast-iron frames to which they are hinged, and the large clinkering door slides vertically in guides and is counterbalanced.

291. Drawings of thermal storage arrangements. Presented by Druitt Halpin, Esq., 1902. M.3246.

The beneficial action of a large volume of water in a steam boiler, in moderating the fluctuations in steam pressure consequent upon variations in the work being done, has long been known, while the practicability of running locomotives for moderate distances solely with the steam obtainable from a reservoir of highly heated water has been repeatedly demonstrated on tramways and in mines.

The thermal storage system employed by Mr. Halpin, while depending upon the same principles as these earlier arrangements, forms a somewhat different application. In the method he patented in 1891–2, which was primarily designed to overcome the difficulties experienced in electric light stations through the great variations in the work required from the plant at various times, the excess of heat received by the boilers when the engine demand for steam is slight is stored in a reservoir of hot water, suitably lagged with non-conducting covering. The reservoir is a vertical cylindrical vessel 30 ft. high by 8 ft. diam.

greater capacity when necessary being secured by increasing the number of such vessels.

The boiler and reservoir pressures are higher than that at which the steam is supplied to the engine, and the thermal storage is represented by the difference in the amount of heat in the reservoir at the temperatures corresponding with the higher and lower pressures respectively. With pressures of 250 and 115 lbs. absolute it is estimated that each pound of water originally in the reservoir will supply ·07 lb. of steam at the lower pressure, which steam is thus available to assist the boilers at the time when the demand exceeds their supplying capacity; furthermore, water from the reservoir can be directly admitted to the boilers so that the feed can at the same time be shut off.

When, moreover, through steam having been withdrawn, the temperature and pressure of the reservoir have fallen, the mass of cooler water it contains is capable of condensing steam from the boiler and thereby storing heat when, through a reduction in the demand, the boilers are supplying more steam than is being required.

These lithographs, however, show a modification of the apparatus patented by Mr. Halpin in 1901, in which a storage reservoir or drum is placed on the top of a horizontal boiler and connected with its shell by a tube of large area which extends nearly to the top of the drum, both vessels being at the same pressure. The feed water, from an injector or pump, is introduced at the top of the drum wherein, as it becomes heated nearly to the steam pressure, it deposits its sediment, thus saving incrustation in the boiler itself. This hot water, taken from above the sediment level, is afterwards allowed to flow into the boiler as feed when an exceptional load comes on, the injector feed being at the same time shut off so as to increase the steaming power. By placing one connection within another only one hole in the boiler and reservoir are required.

BOILER ACCESSORIES AND DETAILS.

In the working of a steam generator much labour and anxiety are saved by suitable arrangements of the stokehold or boiler room, and by the addition of appliances which automatically perform some of the duties that originally fell to the attendant, while, above all, the disastrous results following any temporary or accidental neglect are, by suitable fittings, together with careful examination at frequent intervals, rendered almost impossible.

Furnace Doors and Fire Bars.—Until within the last few years the furnaces of almost all boilers were water jacketed, so that the heat generated should pass directly into the water; under this arrangement the use of large furnace flues became general, and the collapse of such flues under external pressure was a most frequent form of boiler accident, now, however, safely guarded against by various modifications of the flue which give it additional stability. For working at higher pressures, and with the object of getting greater boiler power in a limited space, the water-tube construction is being increasingly adopted for both land and marine work; in

these, if the furnace is water jacketed it is accomplished by placing pipes side by side in contact with each other, but in many cases the furnace sides are simply of brickwork.

The fire-grates in use still consist of an arrangement of bars of cast or wrought iron, but considerable efforts have been made to improve the combustion by increasing the number and diminishing the spaces between the fire bars, so as to give more diffused and finer currents of air. The supply of air under pressure, and the heating of the same by the otherwise waste heat, are devices successfully adopted for increasing the efficiency of the furnace, but these refinements have been chiefly confined to boilers for steam ships in which fuel economy is of the highest importance.

Mechanical Stokers.—These self-acting stoking appliances are being used to an increasing extent, as they save much labour and give more uniform firing than is usually secured by manual labour; they have the additional advantage of preventing the rush of cold air through the furnace, which otherwise takes place when the fire door is open. Their use, however, is at present chiefly confined to land work.

Feed Heaters.—The feed-water of a boiler is sometimes heated in a series of tubes placed in the flue so as to recover the waste heat that was being carried off by the gases to the chimney. In addition to the saving of heat which they effect, feed-water heaters are useful in that much of the mineral matter in the feed-water is deposited in them, instead of in the boiler, where its removal would be more difficult and its presence more objectionable. When the engine is non-condensing, the use of a feed-water heater, through which the exhaust steam passes, results in a considerable saving of fuel, and it is difficult to understand why so many high-pressure engines are still working without some such useful economiser. The term "economiser" has, however, been appropriated by a form of feed-water heater which abstracts waste heat from the furnace gases after they have left the boiler flues, and it is therefore useful for both condensing and non-condensing engines.

Water Gauges.—For very many years the only means of determining the level of the water within a boiler was by means of gauge cocks fitted at different heights on the boiler front, the attendant learning the level by testing whether steam or water came from certain of them. Gauge glasses are now universal, but with the increased pressures frequently used the danger resulting from a burst glass has led to the use of protecting screens of wire or thick glass. In some cases mica is used for the gauge itself; self-closing ball valves are also added to prevent the rush of steam and water continuing after a glass has failed.

The water level in a boiler is usually controlled by an attendant, who turns on the feed when the glass shows it to be necessary and attempts to adjust the feed to the rate of evaporation, but it is becoming general to fit automatic feed regulators. In most water-tube boilers these are especially necessary, as the amount of water contained is small, and its level is not always indicated

by the height of water in the gauge glass. These appliances usually consist of a hollow metal float controlling an equilibrium valve in the feed pipe, or a balanced stone float may be used in the same way, but this is generally applied to blow a whistle or ease a safety valve when the water becomes dangerously low.

Fusible Plugs.—The insertion of a lead rivet was early adopted as a means of reducing the risk of collapse should the water get so low as to expose the crown of the furnace; in the more modern application of the device arrangements are made for ensuring the complete release of the plug in the case of over-heating, and also for the replacement of a plug that has been in use so long as to require renewal.

Safety Valves.—The importance of some means of limiting the pressure within a boiler, so that an explosion shall not follow an irregularity in the supply of steam, was practically learned with the introduction of Savery's engine, with the result that in 1707 Papin introduced a form of lever-weighted safety-valve. When the boiler is not stationary the weight is replaced by a spring, and in all types it is now becoming general to dispense with the lever, the valve being directly loaded by weights or powerful springs; as an additional security it is usual to fit two safety valves, one of which is frequently "locked-up" so that its load cannot be increased without due authority.

Steam Separators and Traps.—Where a large amount of steam is required from a small boiler the ebullition is so violent that particles of water are carried away by the steam, and if this occurs to an excessive extent great damage may be done to the engine in addition to the waste of fuel resulting from the use of wet steam. The steam dome is one of the earliest and best arrangements for preventing excessive priming, but a large collecting pipe, perforated along the upper surface and extending along the top of the steam space, is a device frequently adopted with long stationary boilers. Where wet steam is unavoidable or the steam is travelling through a long length of pipe the water particles distributed through it are separated by a drier, in which the steam is usually projected against some surface upon which the particles of water adhere and slide down to a receptacle from which the accumulated water escapes by an automatic valve, or trap, to the feed tank.

Furnace Doors and Firebars.

292. Boiler furnace door and drawing. Lent by Messrs. W. A. Martin and Co., 1888. M.1936.

This is a form of door for a boiler furnace, patented by Mr. W. A. Martin in 1867. It is hinged at the top, and balanced so that it will stand at any angle at which it may be placed. When it is opened for stoking the fire, it is turned up, so as to stand full open, opening outward; but when it is desired to admit air above the grate, to prevent smoke after putting fresh coal on, the door can be set open a little way

opening inward, in which position its curved surface acts as a deflector, driving the inflowing air down upon the "dead plate" in front of the grate, so that it shall impinge upon the fuel.

293. Model of Perret's furnace. (Scale 1 : 8.) Made by Messrs. Bryan Donkin and Co., 1892. M.2439.

This shows a boiler furnace for utilising dust or refuse fuel, by the assistance of forced draught. It was patented by M. Perret in 1881.

The firebars are made very deep, and their lower edges dip into a water trough below, by which means the bars are kept comparatively cool. An outside cistern with a ball-cock, automatically maintains the height of water in the trough, and a small box outside the furnace has a testing-hole at the top through which the height of the water can be ascertained. The forced blast, which is regulated by a throttle valve, is supplied to the closed ashpit at a pressure of ·5 in. to 1 in. of water, and passes upward through the fuel. The cooling of the bars prevents the adherence of clinkers, and their lower outline avoids the trouble that would otherwise result in casting owing to the varying section.

294. Furnace fire bar. (Scales, full size and 1: 3.) Lent by Messrs. N. Varty and Sons, 1900. M.3134.

This construction of grate-bar was patented in 1895 by Messrs. F. and T. Varty and H. Robinson as a means of improving the combustion in furnaces. From the sides of each bar project curved fins, to convert the horizontal motion of the entering air into a vertical one, while at the same time heating it. The fins of the adjacent bars break joint, so as to give a well distributed draught, while along the centre of each bar is a ledge which facilitates the removal of clinker.

295. Forced draught furnace. (Scale 1 : 4.) Presented by the Horsfall Destructor Co., 1907. M.3487.

This shows a furnace, suitable for burning fuel of low calorific value by means of forced draught, provided also with an arrangement for preventing smoke; it is shown fitted to a Cornish boiler, but can be applied to any type.

The grate is made up, according to the nature of the fuel, either of closely spaced bars or of plates of channel section perforated with a large number of conical holes or slots. Each plate or set of bars forms the cover of a trough into which air is forced by a steam jet of adjustable rectangular cross-section. The steam pipe leading to the jets has a pressure gauge, and a stop valve to throttle the steam to the most economical pressure. The small quantity of ash falling through the fine holes into the trough is removed by a rake of special form. Each section being independently controlled, its efficiency is unaffected by the thickness of the fuel elsewhere in the furnace.

To prevent smoke, a heated current of air is directed by an independently controlled steam jet above the door down upon the gases rising from the fuel near the bridge.

It is stated that with this furnace upwards of 60 lbs. of fuel can be burnt per sq. ft. per hour with greater evaporative efficiency than with natural draught, after allowing for the steam used by the jets.

Mechanical Stokers.

296. Model of travelling furnace grate. (Scale 1 : 8.) Contributed by R. Bodmer, Esq., 1857. M.77.

By this arrangement, patented by Mr. J. G. Bodmer in 1834–43, the fuel, while being burnt, is slowly conveyed from the front to the back of the furnace; in this way it is insured that the gases freely given off from the black coal shall pass over the glowing fuel, and so be burnt before entering the flues. One of these grates, 9·5 ft. long by 30 in. wide, was at work in 1843, at Old Ford, near Bow; another, 15 ft. long by 27 in. wide, was used on the Croydon Railway. The work was satisfactory, and smoke was prevented.

The furnace bars are placed transversely, and are carried by two longitudinal screws between whose threads the ends of the bars loosely rest. These screws are continuously rotated by power, and thus move the bars towards the back of the furnace, where they descend and afterwards engage with the threads of two similar screws below, which bring the bars back again to the front of the furnace, where they are automatically elevated to the grate level and again advanced. In the upper screws the threads are cut "drunken" towards the back of the furnace, so that the bars receive a rocking motion which tends to detach any clinker formed, while the lower screws have an irregularity in their pitch which separates the bars so as to allow any cinders that drop to fall between them.

297. Wall diagrams of Juckes's furnace. Lent by Messrs. Richard Moreland and Son, 1902. M.3229.

These show an improved form of the mechanical stoker patented in 1841 by Mr. John Juckes, which, although most generally applied to under-fired boilers, has also been successfully used with those of the through-furnace-flue class and of the water-tube type.

The chief feature of the furnace is that the fire-bars are in short lengths and pinned together, so as to form the links of a wide pitch chain which is moved by sprocket wheels at an adjustable rate, by ratchet and reduction gearing from an external source of power. The top surface of this travelling grate is maintained level by a series of transverse carrying rollers, and the sag of the lower return portion is restricted in the same way, while the wear of the links can be taken up by adjusting screws which move the bearings of the inner sprocket wheels.

The fuel is contained in a hopper at the front, from which it falls on to the in-going portion of the grate, the depth of fuel thus led in being regulated by an adjustable sliding door. The first portion of the furnace is covered by a low firebrick arch which heats the in-going coal and drives off the most volatile gases, so that they shall be consumed by passing over the full length of the fire. The whole grate and its supports are carried on a truck which can be moved in or out on rails when, as in the case of the brewery copper shown, the fire has to be withdrawn upon the completion of a boil while the charge is being drawn off and a fresh one introduced. This class of furnace is practically smokeless, even when using inferior fuel, and it gives a high evaporative efficiency. The furnace represented is for heating a copper 21 ft. diam. and has a grate area of 55·5 sq. ft.; the gases pass round the

boiler, through flues which give a split draught, and then escape to a chimney, which is shown supported on rolled joists and provided with sliding doors for cleaning purposes.

298. Model of mechanical stoker and furnace bars. (Scale 1 : 8.) Lent by Messrs. T. and T. Vicars, 1887. M.1855.

This construction of machine for feeding the fuel into the furnace and along the grate of a steam boiler was introduced in 1866 by Messrs. Vicars; it has since been extensively used and considerably modified in detail. The general principle of the arrangement is that the coal stored in the hopper above the furnace front is, by the aid of mechanism driven by a small steam engine or from shafting, continually being forced into the furnace front and gradually worked towards the back end of the furnace as the combustion advances; in this way continuous feeding is secured, the undue admission of air while charging is avoided and the smoke from the "green" coal is compelled to pass over glowing fuel.

The stoker is represented as fitted to the front of a Cornish boiler, the furnace flue of which has been cut to show the arrangement of the grate. The fuel is stored in a large hopper above the stoker, from which it is fed by two inclined rectangular plungers, slowly reciprocated by two eccentrics on a counter-shaft driven by a ratchet feed from some source of power; the pawl of the ratchet has a projecting pin resting on an adjustable masking wheel, by which the attendant can regulate the supply of fuel to suit the steam demand. These two plungers work alternately and slowly push fuel on to a short perforated dead plate, from which it falls on to the furnace, alternate bars of which are connected with two crossheads reciprocated horizontally by cams on the counter-shaft. The motion given to the bars is such that, although both sets move backward together, they move forward at different times; in this way the spaces between the bars are freed from clinker, and the mass of fuel is slowly worked towards the further end of the furnace, where the clinker and cinders accumulate and form a bank which acts as a fire bridge, the excess being removed at intervals by raking it from the ash pit.

299. Model of mechanical stoker. (Scale 1 : 12.) Lent by James Proctor, Esq., 1888. M.1921.

In this mechanical stoker, which was originally patented by Mr. Proctor in 1875, and has since been considerably simplified and improved, the feeding is performed by a flap, which jerks the fuel on to the grate in a way resembling hand firing with a shovel, the further distribution of the charge being accomplished by the use of reciprocating fire-bars.

The model shows the stoker fitted to the front of a Lancashire boiler, and feeding from a single coal hopper above, from which the fuel is distributed by a block, reciprocated horizontally along a pipe, to a small chamber at the front of each furnace. In each of these chambers is a flap which is moved away from the furnace by pegs on a revolving crank plate and then rapidly swung forward by the action of a spring thus throwing and distributing the fuel on to the grate in small quantities.

The fire-bars are arranged in pairs alternately fixed and moving the latter receiving a slow combined vertical and horizontal movement from a crank-pin on a shaft driven by worm gearing. The whole of the motions are derived from a countershaft driven from an engine or by other means.

Beneath each automatic feed hopper is a hinged flap for regulating the admission of air, and for use as a fire door should hand-firing be resorted to.

300. Holden's liquid fuel burner. Made by the Great Eastern Railway Co., 1903. M.3292.

Oil as a fuel for steam generators possesses several advantages, the most important of which are that it requires no stoking, is easily conveyed to the furnace, has a high calorific value, and gives a flame that can be immediately and completely adjusted to the demand for steam; it forms no ash, moreover, and consequently exerts no abrasive action upon the fire-box and tubes. These advantages were early recognised, and numerous extensive experiments were carried out at various times: in 1834 by Mr. J. Bourne, in the sixties by Messrs. Richardson, Aydon and others, and by Messrs. Sims and Barff, who tried oil-fuel on a steam yacht; but it was in Russia, about 1874, that oil-fuel first came into extensive use by being successfully applied to locomotives and steam ships.

Several methods of burning oil as fuel have been tried, such as mechanical spraying, air or steam-jet spraying, and pre-vapourising, but that introduced in 1865 by Mr. Aydon, in which the oil is sprayed into the fire-box by a steam jet drawing in air at the same time, is now most generally used, although for marine work it has the disadvantage of carrying off some of the feed water.

The most conspicuous application of oil burning in this country is that perfected on the Great Eastern Railway by Mr. James Holden, who commenced experimenting in 1886. In his arrangement the oil is sprayed into the fire-box by a pair of steam jets, hot or cold air being drawn in through the apparatus at the same time, and additional air introduced by means of a ring steam blower, which also completes the pulverisation of the oil drops. The spray is burnt in the fire-box, over a bed of broken fire-brick, but an extra brick wall is added where the flame impinges, to prevent undue local heating.

The burners shown, one of which is in section, are the latest form of the arrangement patented by Mr. Holden in 1886–99 for use on a locomotive provided with the vacuum brake. Each burner consists of an outer casing containing three concentric cones forming the nozzles through which pass the air, steam, and oil that form the inflammable spray which is directed into the fire-box. As the amount of air thus introduced is insufficient, the spray nozzle is surrounded with a ring of steam jets forming a blower which carries in additional air through the two circular orifices into the fire-box, by which the spray is admitted. The central air inlet of these burners is connected with the train pipe, so that the exhaustive action is utilised in maintaining the vacuum, a ball valve preventing the inrush of air when the apparatus is stopped. If the brake service is of the pressure type this economy is not practicable, but a heated air supply is provided by drawing the air through a coil placed in the smoke box. In order to increase the quantity of oil that can be effectually sprayed by the

two burners, an auxiliary oil supply is led to the end of the spray nozzles, so that oil from it is carried into the furnace with the mixed jet; the supply of oil to the whole of the jet is, however, regulated by a single combined plug and lift valve.

It is estimated that 1 lb. of oil is practically equivalent in evaporating power to from 1·5 to 2 lbs. of coal, and that the most economical oil is the petroleum refuse "astatki," or else coal or oil-gas tar. Similar oil-burning arrangements are used for melting metal in crucible furnaces or on an open hearth.

Feed Water Heaters.

301. Model of fuel economiser. (Scale 1 : 8.) Lent by Messrs. A. Lowcock, Ltd., 1902. Plate VII., No. 4. M.3260.

The name "economiser" is applied to a type of feed-water heater, originally introduced about 1845 but since considerably improved, in which the feed-water before entering the boiler is caused to take up some heat from the waste gases leaving the boiler flue; the apparatus is built into the flues between the boilers and the chimney, and the hot gases play on the outside of pipes through which the feed is being introduced. In the model the boiler represented is of the Lancashire type, and the economiser is arranged in a bye-pass flue provided with suitable valves, so that the boiler may be used either with or without it.

The economiser shown, which embodies improvements patented by Messrs. A. Lowcock and T. Sykes in 1880, and subsequently, is built up of vertical cast-iron pipes whose ends are forced by hydraulic pressure into boxes, those at the top being provided with a cleaning cover over each pipe, while the bottom ones slope and lead to a blow-off cock; where necessary, each nest of pipes is provided with expansion joints and stop valves. The feed-water is forced through the economiser by the boiler pump or injector, entering at the end of the bottom branch pipe furthest from the boilers, and leaving at the end of the top branch pipe nearest the boilers, so that the hottest gas deals with the hottest water.

Each upright pipe is provided with a scraper, which is slowly moved up and down, so as to remove the soot which would otherwise accumulate on it and seriously detract from the efficiency of the economiser. These scrapers are made of chilled cast-iron, and are helical in form; they are worked in balanced groups by chains passing over pulleys moved by worm gearing, the reversals at the ends of the travel being effected by a three-bevel-wheel clutch, moved by a tappet on the worm shaft, and having the clutch lever assisted by a rolling weight which insures complete reversal. The soot scraped off falls into a chamber below the pipes, and is removed at intervals through cast-iron cleaning doors.

The apparatus may be made from four to ten pipes wide and of any length, to suit the number of boilers installed. The feed-water is usually supplied at 32 deg. C., and on leaving the economiser its temperature is about 150 deg. C., but these figures will depend upon the extent to which the boiler is being forced, the working pressure, etc. An indirect advantage of such an accessory is that, in using hard water, most of the impurities are deposited in a soft condition in the economiser,

from which they can be blown out, and thus prevent incrustation in the boiler.

302. Compactum feed-water heater. Lent by J. Kirkaldy, Esq., 1887. M.1873.

This is an apparatus, patented in 1885 by Mr. J. Kirkaldy, for heating the feed-water for a boiler, by means of the exhaust steam ; its peculiarity is the compactness of its arrangement. Four helical coils of water pipe, fitting partly into one another, are enclosed in a narrow chamber through which the steam passes. The pipe is corrugated longitudinally so as to increase the proportion of heating surface to sectional area.

303. Drawing of feed-water heater. Lent by James Atkinson, Esq., 1890. M.2284.

In this feed-water heater, patented by Mr. J. Atkinson in 1877, the exhaust steam from the engine enters at the steam inlet and passes in a direct unimpeded course through a channel provided for it, which is of a similar sectional area throughout, to the steam outlet, from which the exhaust pipe conducts away the steam not utilised in heating the water.

The channel is open at the top to the lower side of the tube plate. Screwed into the tube plate are a number of vertical tubes, open to the exhaust steam at the bottom, but closed at their upper ends, which are left perfectly free to expand or contract without straining. In each of these heating tubes is a small circulating tube leading from near their upper ends to the channel through which the exhaust steam passes, and the mouths are so arranged that the passing steam causes an induced current out of them, and thus out of the upper ends of the heating tubes, removing the air which they contain, or which may be carried in with the exhaust steam, and causing them to be filled with steam. A small portion of the heating tubes projects into the exhaust steam, and assists in diverting the steam into them.

304. Drawing of feed-water heater. Lent by Messrs. Hawksley, Wild, and Co., 1894. M.2731.

In this form of feed-water heater the water passes up through vertical tubes, and then down similar tubes to the boiler feed pipe below.

The tubes are enclosed in a vertical cylindrical shell through which the exhaust steam is passed, a vertical baffle plate directing the steam over the surfaces of the tubes. The drawing also shows a modified form, in which the steam passes through the tubes and the water is outside them, but both arrangements leave the tubes free to expand independently of the outside shell.

305. Model of feed-water heater. (Scale 1 : 8.) Lent by Messrs. Joseph Wright and Co., 1901. M.3190.

In this heater, which was patented by Mr. R. Berryman in 1871–6, the exhaust steam from the engine is passed through a group of U-tubes, secured into a V-shaped tube plate which serves also as a diaphragm between the steam inlet and outlet; improvements in detail, including the combination with it of an oil separator, have since been added by the makers.

The upper part of the apparatus is made of boiler plate and surrounds the tubes, but can be lifted off for cleaning them externally; into it the feed water is introduced, the deposited impurities settling in the V-shaped depression of the tube plate, from whence they are washed out at intervals. Beneath this shell is the middle belt, into which the steam enters on one side and, after passing through the tubes, is condensed into water which collects in the base. The base is divided by a diaphragm, which also supports the tube plate and has openings below through which any remaining steam can pass away; the collected water is discharged by a siphon when it exceeds a certain depth.

306. Fresh water condenser. Lent by Messrs. Royles, Ltd., 1902. M.3257.

This condenser embodies improvements patented by Mr. O. M. Row in 1891, and in the form represented would be used in connection with a boiler or "evaporator," for obtaining fresh water from sea water; with slight modifications, however, the arrangement can be converted into a feed-water heater.

The condenser consists of an outer casing containing a number of vertical tubes, the ends of which are either expanded into a tube plate or made tight by some form of screw joint; the cooling water circulates within the casing, its inlet and outlet being at the side, while the steam or vapour to be condensed passes through the tubes, entering at the top and being discharged as condensed feed or drinking water at the bottom. If the water is required for drinking purposes it is aerated by the pipe shown, the air entering through the hooded orifice and passing into the condenser, where it mixes with, and is partially absorbed by, the distilled water.

The chief feature of this condenser is the form of tube employed, of which a short portion of an actual length is shown. This "Row" tube is indented at intervals along its length, so as to reduce the section at each indentation to a narrow rectangle at right angles to the adjacent ones; in this way the free passage along the tube of the vapour and water, both inside and outside, is checked, and the formation of steady streams avoided, thus increasing the transference of heat by the greater amount of impact contact secured.

307. Model of boiler cleaner. (Scale 1 : 12.) Lent by Messrs. A. Ross, Hotchkiss and Co., 1906. M.3466.

This is an arrangement in which the circulation of the water in the boiler is usefully employed in order to remove foreign matter. It was patented in 1883 by Mr. J. F. Hotchkiss and in the model it is shown as applied to a Lancashire boiler, but it may be fitted on any tubular boiler. It consists of a cast iron spherical vessel, placed on the top of the boiler, preferably at the back end, and connected with it by two stand pipes, both being continued internally. The up-flow pipe ends in a horizontal funnel-shaped mouth, which is so placed that its lower edge is not higher than the low-water level of the boiler. The mouth is directed to the front end of the boiler in order to receive the surface currents of hot water flowing towards it. The return pipe is continued through the boiler shell as far below the level of the

funnel mouth as the construction of the boiler will permit. From the bottom of the spherical vessel a blow-off pipe is led to a convenient place for discharging. When the boiler is in use a continuous circulation is set up through the spherical vessel, convection causing the hot water to rise in the funnel-mouthed pipe, and, becoming cooled, to pass through the return pipe to the bottom of the boiler. The impurities in the boiler water driven to the water level by ebullition are carried with the ascending water into the external and comparatively quiet vessel on the top where the sediment is precipitated. This deposition is assisted by a vertical diaphragm or baffle inside the sphere and cast with it, which prevents undue agitation of the water. The baffle also, by giving the water a longer course, allows greater time for the sediment to settle. The deposit may then be blown off as often as necessary. An air blow-off cock is provided at the top of the vessel. An incidental advantage claimed for the apparatus is that circulation in the boiler is greatly assisted, a continual stream of hot water being delivered to the bottom of the boiler.

Further improvements in the apparatus were patented by Mr. A. Ross in 1894, one of the chief of which was the provision of a charging orifice in the spherical vessel. Some time would, of necessity, elapse before circulation was set up in this vessel, if it were left to charge itself, but by this addition the time lost is obviated.

Water Gauges and Fusible Plugs.

308. Water gauge and drawing. Lent by Messrs. Llewellins and James, 1888. M.1882.

This is a water gauge, patented by Messrs. Landerhohn and Nelson in 1885, for showing the level of water in a steam boiler by means of a glass tube. The drawing shows the relative positions of the parts, with the glass tube in place, portions being in section to show the construction of the valves, which constitutes the peculiarity of this gauge. In place of the ordinary cocks, conical valves are employed, which automatically close and prevent the escape of steam and water in case of a glass tube breaking. On the drawing is given a detailed description with reference letters.

309. Water gauge. Lent by Messrs. J. Dewrance and Co., 1880. M.2507.

In this arrangement of water gauge the glass tube is held in an asbestos packed gland at each end, and the three cocks, by which communication with the steam and water spaces of the boiler is closed and the blow-off opened, are all similarly packed, the intention being to obtain greater tightness than the simple metal to metal fittings permanently afford.

310. Fusible plugs. Lent by Messrs. Allan, Harrison, and Co., 1862. M.709.

Fusible plugs have long been used as an additional safety appliance to steam boilers.

This example is in the form of a valve, cottered down. The seating of the valve carries the plug well above the furnace crown and the valve or cap is drilled with a number of holes, each of which is plugged with a fusible alloy. The cotter permits the valve to be easily replaced when necessary, the plug, however, being inserted from the water side.

311. Copper cap fusible plugs. Lent by Messrs. W. H. Bailey and Co., 1888. M.1886.

This plug consists of a socket screwed for fixing to the furnace crown and provided above with a nut. It was patented in 1885 by Sir. W. H. Bailey. Fusible metal, in the form of a thick disc, covered above with a thin copper cap, is secured to the socket by the nut as shown in the adjacent drawing. The copper cap is intended to protect the fusible alloy from any chemical action of the water and to insure a sudden and complete release of the plug.

312. Fusible plugs. Lent by the National Boiler and General Insurance Co., 1888. M.1968–9.

In this construction, patented in 1888 by Mr. H. Hiller, the fusible alloy is used to secure a core into a readily removable plug screwed into a gun-metal seating, which is screwed into the furnace crown. The plug is provided with a bevelled edge similar to that of a valve, so as to insure a tight joint, and the core is formed with a flange, which protects the fusible metal from the direct action of the fire, and prevents its gradual escape. The exterior of the core and the interior of the plug are grooved so that the core is retained in position against the pressure of the steam by the shearing resistance of the fusible alloy.

A complete plug, fixed in a portion of a furnace crown, together with one in section, are shown; these are renewable from the water side. A similar plug and section show the modification necessary when the plug is made renewable from the furnace side.

313. Fusible plug. Presented by the Vulcan Boiler and General Insurance Co., Ltd., 1906. M.3464.

This safety device for the furnaces of internally fired boilers was patented in 1904 by Mr. C. Bullock, and is of the pattern approved by the Vulcan Co.

It consists of a serrated copper cone embedded in an annulus of fusible alloy in a cap screwed into the body of the plug. This alloy is protected from non-conducting incrustation, etc., by a cavity therein, the opening of which is filled by the spherical end of the stem of the cone; this serves also as a conductor of heat. When the alloy is melted the cone is not blown out, but after dropping a short distance, is stopped by internal ribs, thus leaving a passage for steam.

The size shown is the largest made and is suitable for Lancashire and large Cornish boilers; it is inserted from the water side of the furnace. A pattern for locomotive boilers, inserted from the fire side, is also made.

Safety Valves, Steam Separators, and Traps.

314. Wilson-Klotz safety valve. Lent by John C. Wilson, Esq., 1889. M.2283.

This safety valve, patented in 1876 by Mr. J. C. Wilson, is so constructed that the full pressure of the steam is exerted on the area of the valve even when blowing off freely. The steam pressure is maintained under the crown of the valve by a central pipe reaching well into the steam space of the boiler, while the escaping steam passes to the lip of the valve in the ordinary way. The spring is enclosed in a metal casing to prevent its being tampered with, and also to shield it from the escaping steam.

315. Vaughan's steam trap. Received 1886. M.2533.

This apparatus is one of a class largely used for automatically removing the water formed by the condensation of steam in long lengths of steam pipes, steam jackets, etc., without allowing steam to escape.

The sectioned example shown is a steam trap for a 3-in. pipe, and consists of a cast-iron vessel fitted with two deflectors by which the steam and its contained water are thrown into the lower portion of the vessel where the water settles by gravity. From the chamber the water escapes by a pipe, communicating with an automatic valve so constructed that it will allow the water to pass but not the steam. This is accomplished by using a horizontal iron pipe carrying at its end a hand-wheel and a stop-valve, and having within it a copper pipe which carries the seat of the valve at one end but is rigidly fixed only at the opposite extremity. The valve is slightly withdrawn from its seat so as to let the water escape, but when all the water is exhausted and steam enters the copper pipe the greater expansion of copper (about 50 per cent. more than iron) elongates the internal tube sufficiently to close the valve. After a while the further accumulation of water in the collecting chamber cools the copper tube sufficiently to open the valve again. By opening the valve wide a complete blow through for scouring purposes can be effected.

316. Diagram model of Royle's steam trap. Lent by J. J. Royle, Esq., 1887. M.1864.

This steam trap is constructed so that the mechanism is outside the steam pipes, and not being subjected to the steam pressure, can be readily examined. It was patented in 1882 by Mr. J. J. Royle.

The section shown represents a cast-iron cistern closed by a cover, and provided with an inlet on one side and a syphon discharge on the other. The inlet is closed by a small valve controlled by a powerful float, so that it can resist the steam pressure. The valve leaks slightly, and so the water drains into the cistern, and thus raises the float. This further opens the valve, which then admits more water, and finally a little steam that then forces the accumulated water out of the trap by the siphon pipe. A partition divides the lower portion of the cistern into two parts, and the entering water fills the first portion before reaching the float. A small hole in this portion allows a slight passage of water to take place, and this is useful in lifting the float after blowing

through. There is a small dead-weighted air-valve on the cover which allows any accumulated air to escape, but an expansion rod closes it if steam attempts to pass.

317. McDougall's steam trap. Lent by the Chadderton Iron Works Co., 1888. M.1952.

This steam trap was patented in 1885 by Messrs. I. S. and J. T. McDougall, and consists of a closed cast-iron box containing a counterbalanced fire-brick float, which controls a horizontal piston valve arranged in the lower portion of the box, and communicating with a drain pipe. The trap is connected with the lower portion of the steam pipe to be drained, and when the water collected in the box reaches a sufficient depth the float lifts and allows some to escape. An external handle is provided for moving the float lever by hand when desired, for testing, without having to open the trap. The attached sectional drawings show the internal construction.

318. Steam trap. Presented by Messrs. Holden and Brooke, 1896. M.2944.

This apparatus, known as the "Sirius" trap, consists of a light cast-iron box, which contains the valve and seating, together with a Bourdon tube. The valve is connected with the lower portion of a steam pipe to be drained by about 10 ft. of pipe, in which the collected water is cooled to less that 212 deg. F. This water enters the chamber, and flows out through a pipe attached to the other end. The Bourdon tube is of tempered steel and hermetically sealed, but contains a volatile liquid the pressure of the vapour from which rises very rapidly with increase of temperature, so that the difference in the vapour pressure at 210 deg. F. and at 212 deg. F. is sufficient to give a considerable variation in the span of the tube.

The valve and tube are connected together, and pressed by an external set screw against the reaction of a spring towards the valve seat, so that the adjustment can be accurately made. When cool the valve is fully open, so that the steam pipe is drained on starting; the valve remains open until steam enters the trap and causes the Bourdon tube to lengthen so as to completely close the valve, which remains closed until the temperature falls below 212 deg. F. Unless the discharge from the trap is to be at a higher level the apparatus is free from internal pressure.

319. Steam trap. Lent by the United Asbestos Co., Ltd., 1905. M.3393.

This is an example of an expansion steam-trap patented by Mr. J. E. L. Ogden in 1898, and improved in 1904–5. Its action depends on the expansion and contraction of a tube operating the valve through which the condensed water is discharged.

It consists of a tube of brass, or other metal with a high co-efficient of expansion, connected at one end with a valve casing, the other end being secured to a flange attached to the steam piping which it is required to drain. Two iron rods are mounted with their inner ends carried in a collar pivoted on the end flange, and with their outer ends

carried, one against the valve casing, and the other against the shorter arm of a spring-loaded lever. The lever operating against the steam pressure bears against the discharge valve spindle and keeps the valve closed.

When the trap is cold, it is arranged that the valve is open owing to the pressure of the upper iron rod on the shorter arm of the bell-crank lever. Steam then passes freely through the trap, raising the temperature of the brass tube, which, expanding, relieves the pressure of the iron rod on the lever, and allows the spring to shut the valve. Condensed water then collects in the brass tube, and, as its temperature falls, the tube contracts, thus opening the valve, when the same series of operations recurs. The effect of the expansion of the brass tube is magnified first, by the bell-crank lever having unequal arms, and then it is doubled by having a pair of iron rods and making the collar against which they bear pivot about the end flange on knife edges.

320. Steam trap. Presented by Messrs. Geipel and Lange, 1906. M.3462.

This steam trap, patented in 1893 by Mr. W. Geipel, depends for its action upon the difference in the co-efficients of expansion of brass and iron. In the body of the trap are two tubes arranged to form two sides of an isosceles triangle ; at the apex is situated the valve, whilst the third side is the distance between the ends of the tubes. These ends are fixed in the body of the trap whilst the apex of the triangle is free to move. One end of a spring-controlled lever presses against the valve spindle, which, together with the valve and its shell, is free to move when caused to do so by the expansion of the tubes. The valve is open when the trap is cool, free communication being then established between the steam inlet pipe (brass) and the water outlet (iron). When in use, steam in the brass pipe causes it to expand more than the iron pipe, and the vertex of the triangle, which is practically the valve and its seat, moves, and closes the valve. This position continues until sufficient water collects in the steam pipe to cool it, when its contraction again opens the valve and the water is automatically blown through. Varying pressures of steam are allowed for, as a pressure sufficiently high to cause large movement of the valve would only press the spindle back and compress the spring. The spring is adjusted by means of nuts to keep the valve closed, when in use against the normal steam pressure.

This trap may be used in any position, and may be blown through by hand on depressing the lever. The example shown is the smallest size made and has a discharge capacity of 250 galls. per hour.

321. Centrifugal steam separator and drawing. Lent by J. C. R. Okes, Esq., 1888. M.1890–1.

This apparatus, patented in 1885 by Messrs. C. V. Boys and H. H. Cunynghame, is for intercepting and separating the water, which is held in suspension in steam from ordinary steam boilers, in order to enable engines to be supplied with steam as dry as possible.

The wet steam, entering the separator through an inlet near the top at a tangent to the circle, whirls round with great rapidity, throwing the drops of water by centrifugal force against the sides of the separator,

whence they run down to the bottom, while the steam passes out through a central outlet at the top, and away to the engine. A glass tube or water gauge may be fixed at the side to show the level of the accumulating water, which may be run off through the bottom valve at intervals by an attendant; or a drain pipe from the bottom may be carried to an automatic steam trap.

322. McDougall's dirt separator. Lent by the Chadderton Iron Works Co., 1888. M.1953.

This is a form of trap for removing from steam any water or solid matter mechanically carried along from the boiler or steam pipes. It consists of a circular vessel, closed with a removable cover, and divided into two chambers by a central diaphragm, which is perforated and covered with a metal gauze screen. The steam enters the vessel tangentially, then passes through the screen and onwards to the engine, the screen intercepting any solid matter, whilst a recess around the screen collects the water and delivers it to a drain pipe.

323. Examples of boiler scale. Presented by the Institute of Naval Architects and S. J. Rowan, Esq., 1871 and 1881. M.2519–20.

The flat piece of boiler scale was taken from the flue of a Lancashire boiler, where it covered three rivets. It has been ground down and polished so as to show the varying stratification, which results from differences in the feed-water and the infrequency with which the boiler is blown out.

The cylindrical specimens are short sections of horizontal water tubes, and show how the area has been contracted by such mineral deposits. The bad heat-conducting properties of the scale are, however, the chief cause of the injuries which result from its accumulation.

324. Non-conducting compositions. Presented by Messrs. F. Leroy and Co., & Messrs. A. Haacke & Co., 1887. M.1857 and 1872.

These compounds are extensively used for covering cylinders, boilers, and steam pipes, with the object of diminishing the serious loss of heat which takes place when the surfaces are exposed to the atmosphere. The materials employed, in addition to being poor conductors, must be incombustible, and when dry should be hard enough to resist a certain amount of rough usage. They are applied, in the form of paste, to the hot surface to be protected, and, owing to the introduction of a fibrous ingredient, possess sufficient tenacity to remain in position without additional support; when dry the surface is smoothed down and finally coated with a thick paint, which prevents subsequent softening should water accidentally fall on it.

HEAT ENGINES OTHER THAN STEAM ENGINES.

The changes in the pressure or volume of a mass of air consequent upon its being heated or cooled have been utilised as a means of performing work by the combustion of fuel, in the

so-called "caloric" or hot-air engine. The earliest actual motor of this kind was that designed by Sir G. Cayley in 1807, in which the heated air passed directly from the furnace to the cylinder, where it did work while expanding down to atmospheric pressure, and was then finally discharged. Mechanical difficulties, chiefly resulting from the high temperatures employed, prevented any extensive adoption of this engine, but a few years ago a modification of the system was followed in an engine which attained considerable success; the modern gas engine also resembles it in certain features.

In 1826 Dr. R. Stirling introduced an air engine in which the heat was distributed by means of a "displacer" which moved the mass of air to and fro between the hot and the cold portions of the apparatus; he also compressed the air before heating it, and in this way made a distinct advance in the economy and compactness of the engine. His design is of additional interest in that it was a practical attempt to construct an engine working similarly to the theoretical perfect heat engine, in which the cycle of operations is closed, the same mass of air being used throughout. Stirling was also the first to apply a "regenerator" to absorb and restore alternately some of the heat of the mass of working fluid, and in this way he greatly improved the practical efficiency of this class of motor.

John Ericsson in 1834 constructed an engine somewhat resembling that of Cayley, while in 1852 he built some large caloric engines and adapted them to the propulsion of ships; but since his time the use of large engines of this class has been abandoned, the modern hot-air motor seldom exceeding 1 H.P. The absolute safety and comparative efficiency of the small engines has rendered them of considerable practical use for domestic purposes and light pumping, while for similar reasons the larger caloric engines have been employed as motors in lighthouses and other isolated situations.

The low maximum temperature permissible in a hot-air engine limits the efficiency and causes the machine to be bulky for the power generated; but by heating the air by exploding within it a gaseous mixture, the internal combustion air engine is arrived at, which, in the form of the gas or oil engine, is being so generally adopted. In the case of gas engines using producer gas or the waste gases from blast furnaces the resemblance to the earliest air engine is perhaps more noticeable than in the smaller ones using gas from the mains.

The earliest internal combustion engine was the gun, while as a means of obtaining mechanical power the explosion of gunpowder was utilised in 1678–89 by Hautefeuille, Huyghens and Papin. The explosion of inflammable gases was similarly utilised by R. Street in 1794, and, in 1823 S. Brown introduced his vacuum gas engine for raising water by atmospheric pressure. It was not, however, till 1850 that J. J. E. Lenoir produced the first mechanically successful gas engine, and it worked with a cycle resembling that of a steam engine (*see* No. 330). It was followed by a similar engine by

Pierre Hugon (*see* No. 331) and both were double-acting, but owing to the heavy gas consumption they were of but limited application and were generally superseded by the more economical Otto and Langen engine of 1867 (*see* No. 332).

The greatest improvement in the internal combustion engine was, however, that practically introduced in 1876 by Dr. N. A. Otto when he compressed the explosive mixture in the working cylinder before igniting it, as had been proposed by William Barnett in 1838. By this system a much more diluted mixture can be fired, and this gives a quieter explosion and a more sustained pressure during the working stroke, while as the engine runs at a high speed, the fly-wheel action is generally sufficient to correct the fluctuations arising from there being but one explosion for four strokes of the piston. This method of working has now been adopted in almost all gas and oil engines, the later improvements being in the direction of still higher compression and the substitution of lift for slide valves. There has been a steady increase, in the size and power of gas engines; in the larger examples two or more working cylinders are usually employed so as to secure more uniform driving; these have, moreover, been frequently supplied with some cheap form of gas made by decomposing water by incandescent fuel (*see* Cat. Part II.), and in this way gas power plants are now working which compare favourably with the most economical steam installations.

When the vapour of naphtha or petroleum is used in place of gas in the explosive mixture the motor is known as an oil engine, but the Otto cycle is that followed. The introduction of the petrol motor is to a large extent due to Herr G. Daimler, who in 1884 brought out a light and compact high-speed oil engine; this was developed by Messrs. Panhard and Levassor, who in 1895 devised the form which has since been generally adopted. In common with all internal combustion engines, however, nearly 50 per cent. of the total heat available is carried away by the means adopted to limit the temperature of the cylinder walls and the working parts. Some attempts at compound working with explosion engines and of further extending the expansion have been made, but up to the present it is not clear that anything superior to the single-acting engine has been produced.

Hot-Air Engines.

325. Model of hot-air engine. (Scale 1 : 8.) Presented by P. R. Hodge, Esq., 1867. M.1122.

This engine is of the original type designed by Sir G. Cayley in 1807, in which a closed furnace is employed and two cylinders: a small or cold cylinder, forcing air into and around the furnace, and a larger one into which this heated air is admitted to perform the working strokes, afterwards discharging into the atmosphere.

The model embodies improvements patented by Mr. H. Messer in 1863–4, and has the hot cylinder and the furnace arranged in a rectangular base with the space between them filled with non-conducting

material. The furnace itself is a fire-brick chamber with a perforated bottom, closed above by a removable charging door. Air from the atmosphere is, by the cold cylinder, pumped into the casing of the furnace where it is heated, while some of it maintains the combustion of the fuel. The heated air and gases then pass to the hot cylinder, where, on account of their greater volume, they perform much more work than was absorbed in working the air pump, the difference being available power for overcoming the friction of the engine and doing external work. The cylinders are both single acting, and are connected with opposite cranks on a shaft above. The admission and exhaust valves of the hot cylinder are of the drop type, and are controlled by cams operated by an eccentric on the crank-shaft.

326. Motion diagram of Buckett's hot-air engine. (Scale 1 : 2.) Made by Messrs. H. and T. C. Batchelor, 1889. M.2272.

This engine is of the type originally patented in 1807 by Sir George Cayley, but in the form shown was commercially introduced by Mr. Buckett about 1880. The engine has a cold-air cylinder above the crank-shaft and a large hot-air cylinder below, while the furnace is on one side enclosed in an air-tight chamber; the fuel, when required, is supplied through a valve and distributing cone arranged above the furnace and provided with an air lock in which the fuel is stored. The speed is controlled by a governor and slide valve by which the air, pumped from the atmosphere by the upper cylinder, is distributed between the fire-box and the ash-pit, thus regulating the rate of combustion according to the work being done. The supply of heated air and the products of combustion pass from the furnace to the lower cylinder; the former is controlled by a drop valve worked from a cam on the crank-shaft, a similar valve controlling the exhaust.

At a trial of a double engine of this type, with cylinders 18 in. and 24 in. diam. by 16 in. stroke, the gross indicated H.P. was 41·2, of which the pump used 21, leaving 20·2 effective H.P., of which 14·4, or 71 per cent., was obtained at the brake. The mean pressures on the pistons were 16·7 and 18·5 lbs. per sq. in. respectively, and the coke consumption was 2·54 lbs. per brake H.P.

327. Bailey's hot-air engine (working). Lent by Messrs. W. H. Bailey and Co., 1894. M.2568.

This engine is constructed on Stirling's principle, and after Lehmann and Laubereau's patent. It consists of a long cylinder, formed of a closed steel heater at one end, which is surrounded by a furnace, and at the other end of a larger cylinder, enclosed in a water-jacket, by which this end is kept cool. The cold end is fitted with an air-tight piston, which, through two connecting-rods and a weigh-shaft is coupled to a crank on the fly-wheel shaft. To another crank-pin a second weigh-shaft is coupled, and this is connected with a rod passing through a gland in the piston, and attached to the "displacer." This displacer is a loosely-fitting plunger, which is supported by a roller in the cylinder, and its office is to push the air from the hot end of the cylinder to the cold end, and back again, as required. The only valve is a small one, fixed to the cylinder and opening inward, so that any air lost by leakage is replaced whenever the internal pressure falls below that of the atmosphere.

The same air is worked continuously, being alternately heated and cooled during each revolution of the crank-shaft. At the commencement of the outward stroke of the piston the displacer is at the cool end of the cylinder, and the bulk of the air, which is accordingly at the hot end, is being heated, so increasing in pressure and driving the piston outward. This movement rotates the crank-shaft, and so moves the displacer towards the hot end, thus causing the hot air to pass to the cool end of the cylinder, where the pressure falls through the reduction of temperature due to the cold water jacket, and the return stroke of the piston then takes place, under the action of the fly-wheel. The work given off is the difference between that done by the air during the outward stroke of the piston and that done upon it during the inward stroke.

In an engine of this kind, with a cylinder 14·6 in. diam., and a stroke of 6·87 in., when running at 106 revs. per min., the brake H.P. was 1·3, and the maximum internal pressure 15 lbs. above atmosphere. The mechanical efficiency was 55 per cent., and the coal used 10 lbs. per hour. Such engines are made in sizes ranging from ·25 to 2·5 H.P.

328. Model of Rider's hot-air engine. (Scale 1 : 2.) Lent by Messrs. Hayward Tyler and Co., 1887. Plate VII., No. 5.

M.1871.

This regenerative hot-air engine was patented by Mr. A. K. Rider in 1875. It has two vertical plungers of equal diameter, connected with two overhanging cranks set at right angles on a fly-wheel shaft. The plungers work within two cylindrical chambers, one chamber being kept cool by a water jacket, and the other being heated from below by a furnace, which, in the model, is replaced by a gas burner. The two chambers are in free communication by a connecting-box, which, however, is filled with a number of thin cast-iron plates, so that a large expanse of metal surface is presented to any air passing through this box, which is the regenerator. The stroke of the hot plunger is considerably longer than that of the cold one, so that, although the pressures under the plungers are always equal, the volume displaced by the hot plunger is the greater. A constant weight of air is enclosed between the two plungers, but as the crank-shaft revolves this air is being passed from one chamber to the other through the regenerator. The arrangement of the cranks is such that during the upward strokes of the plungers more of the air is in the hot chamber, and consequently the common pressure is higher than when the plungers are returning. The difference between the power exerted in the upward strokes and that absorbed by the return strokes gives the useful work. In passing through the regenerator the air from the hot chamber leaves some of its heat, which it absorbs again on its return passage, the same air being passed backward and forward continuously, and its pressure rising and falling with each revolution. To replace any loss through leakage a small air valve opening inward is fitted, and through this, air enters if at any portion of the cycle the internal pressure falls below that of the atmosphere. A small pump is connected with the cold plunger to maintain the circulation round the cold chamber, and to do useful pumping work when this is required. Such engines run at about 120 revs. per min., and are extensively used where a small motor is required and skilled attendance is not available, the absence of danger of explosion being a valuable feature.

329. Lowne atmospheric engines. Lent by Messrs. Hardy and Padmore, Ltd., 1905. M.3387–8.

These engines are of the construction patented by Mr. R. M. Lowne in 1889 and 1897. The motive power is obtained by drawing a flame into a cylinder and then cooling the hot gases so that they contract, form a partial vacuum, and allow the atmospheric pressure to force in the piston.

Each engine is provided with a vertical water-jacketed single-acting cylinder, and a trunk piston working through a gland packed with asbestos and having a thin steel band for a rubbing surface. The inner end of the trunk is guided by a ring fitting the cylinder and the outer end by guides on the framing. The flap valve at the top of the cylinder is open during the down-stroke of the piston, and the gas or other flame arranged to play around its seating is drawn into the cylinder; it closes before the end of the stroke, allowing the imprisoned gases to burn out and cool down in time for the up, or working stroke. The piston drives a crank-shaft, with fly-wheel and pulleys, by means of a jointed connecting-rod, the joint being attached to a radius-rod which takes from the cylinder and guides the oblique thrust of the short lower portion of the connecting-rod, and also serves to operate the valve. The valve is lifted by a lever on a rocking shaft which is moved by the valve-rod through a spring connection, so that the valve is enabled to pause on its seat after closing, and is kept closed by the atmospheric pressure during the up-stroke. When the internal and external pressures balance it again opens. The time of closing the valve, thus changing the speed of the engine, is adjusted by turning a nut on the valve-rod. The engine will run equally well in either direction. The water-jacket is connected with a tank and natural circulation is arranged for.

The larger engine is fitted with a fuel tank and a burner suitable for burning petroleum; it has a cylinder 3 in. diam. by 7 in. stroke and is rated at ·125 brake H.P. In the smaller engine the flame is supplied by a Bunsen gas burner. The cylinder is 2 in. diam. by 4·75 in. stroke and with an average vacuum of 5 lbs. per sq. in. is estimated to give about ·067 brake H.P. At a test one of these engines gave nearly ·1 H.P. at 480 revs. per min. on a consumption of about 100 cub. ft. of coal gas per brake H.P. hour.

Gas and Oil Engines.

330. Lenoir's gas engine. Made by the Reading Ironworks Co. Received 1865. Plate VII., No. 6. M.986.

This engine was patented by Mons. J. J. E. Lenoir in 1860, and, although embodying no features not then already known, was the first practically successful gas engine.

To start the engine, the fly-wheel is pulled round, thus moving the piston, which draws into the cylinder a mixture of gas and air through about half its stroke; the mixture is then exploded by an electric spark, and propels the piston to the end of its stroke, the pressure meanwhile falling, by cooling and expansion, to that of the atmosphere when exhaust takes place. In the return stroke the process is repeated, the action of the engine resembling that of the double-acting steam

engine, and having a one-stroke cycle. The cylinder and covers are cooled by circulating water. The firing electricity was supplied by two Bunsen batteries and an induction coil, the circuit being completed at the right intervals by contact pieces on an insulating disc on the crank-shaft; the ignition sparks leaped across the space between two wires carried ·15 in. apart in a porcelain holder.

The engine shown is of ·5 nominal H.P., and was used for two and a half years in this Museum. The cylinder is 5·5 in. diam. by 8·5 in. stroke, and at 110 revs. per min. indicated 1 H.P. Prof. Tresca found that a 1 H.P. engine of this type used 96 cub. ft. of Paris gas per H.P. per hour, at 94 revs. per min., the charge being 7·5 of air to one of gas.

331. Hugon's gas engine. Made by F. B. Vallance. Esq. Received 1868. M.1098.

This engine was patented by Mons. P. Hugon in 1865, but he had then been working at the subject for some years. The only important difference between it and the Lenoir is that the ignition is accomplished by an external flame, instead of by electricity; it was, however, the first engine in which ignition by flame was successfully accomplished.

The igniting flame is carried to and fro in a cavity inside a slide valve, moved by a cam so as to get a rapid cut-off, and permanent lights are maintained at the ends of the valve to re-light the flame ports after each explosion. The gas was supplied to the cylinder by rubber bellows, worked by an eccentric on the crank-shaft. This arrangement is now missing, as it was replaced by the rack and pinion valve gear now shown.

This engine has a cylinder 8·2 in. diam. by 10 in. stroke, and was nominally of ·5 H.P. It worked in the Museum from 1868 to 1880, and at 75 revs. per min. indicated ·78 H.P., with a mean pressure of 3·9 lbs. per sq. in., and a maximum of 25 lbs. Prof. Tresca found the gas consumption in a similar example to be 85 cub. ft. per brake H.P. hour.

332. Atmospheric gas engine. Presented by W. J. Crossley, Esq. 1897. Plate VII., No. 7. M.1856.

The feature of this engine is that it has a " free " piston—an arrangement that was first proposed for a gas engine in 1857, but only brought into a practical form by Herrn. E. Langen and N. A. Otto under their patent of 1866. The machine was noisy and limited to small sizes, but the gas consumption being much less than in any previous form of engine, led to its extensive adoption, so that it is generally considered to be the first commercially successful gas engine. The example shown was the first engine of the kind made in Britain.

The cycle of operations in the engine is as follows :—

(*a*) The piston is lifted about one-tenth of its travel by the momentum of the fly-wheel, thus drawing in a charge of gas and air.

(*b*) The charge is ignited by flame carried in by a slide valve.

(*c*) Under the impulse of the explosion, the piston shoots upward nearly to the top of the cylinder, the pressure in which falls by expansion to about 4 lbs. absolute, while absorbing the energy of the piston.

(*d*) The piston descends by its own weight and the atmospheric pressure, and in doing so causes a roller-clutch on a spur wheel gearing with

a rack on the piston-rod to engage, so that the fly-wheel shaft shall be driven by the piston; during this down-stroke the pressure increases from 4 lbs. absolute to that of the atmosphere, and averages 7 lbs. per sq. in. effective throughout the stroke.

(*e*) When the piston is near the bottom of the cylinder, the pressure rises above atmospheric, and the stroke is completed by the weight of the piston and rack, and the products of combustion are expelled.

(*f*) The fly-wheel now continues running freely till its speed, as determined by a centrifugal governor, falls below a certain limit when a trip gear causes the piston to be lifted the short distance required to recommence the cycle.

Ignition is performed by an external gas jet, near a pocket in the slide valve by which the charge is admitted; this pocket carries flame to the charge, thus igniting it without allowing any escape. The valve also connects the interior of the cylinder with the exhaust pipe, and a valve in the latter controlled by the governor throttles the discharge, and so defers the next stroke until the speed has fallen below normal. To run the engine empty about four explosions per minute are necessary, and at full power 30 to 35 are made, so that about 28 explosions per minute are available for useful work under the control of the governor.

The example shown has a cylinder 6·25 in. diam., and an average stroke of 39 in.; it was rated at ·5 H.P., and the gas consumption was about 26 cub. ft. per brake H.P. hour.

333. Bisschop's gas engine. Lent by Messrs. J. E. H. Andrew and Co., 1888. M.1949.

This engine was introduced by Mons. A. de Bisschop about 1870-4, and was extensively used for many years as a small motor of from 1·5 to 4 man power; the example shows the smallest size. It has a single vertical cylinder with a return connecting-rod working on to a crank; the crank-shaft is, however, on one side of the axis of the cylinder, so that at the time of the explosion, and when, therefore, exerting its maximum pressure, the connecting-rod is nearly vertical and at right angles to the crank. The cylinder is single-acting, and draws in a charge of gas and air during about one-half of its up-stroke, through separate ports each provided with a non-return valve consisting of a perforated metal cover supporting a sheet of rubber, which is forced away when the pressure within is less than without; the charge is then ignited by an external gas flame sucked into a small side passage, which is opened momentarily. The cylinder is cooled by external gills or radiators, and has no water jacket. One of these small non-compression engines required about 120 cub. ft. of gas per brake H.P. hour.

334. Rotary gas engine. Received 1886. M.1636.

This form of gas engine was patented by Mr. S. Ford in 1874. The working chamber is a water-jacketed horizontal cylinder, with a crescent-shaped block or abutment secured to it on one side. Concentric with the cylinder is a fly-wheel shaft, carrying within the chamber a cylindrical drum, the diameter of which is such that the drum touches the abutment. Through the drum is a longitudinal diametral slot, fitted with two blades or pistons, which, by an intervening spring, mutually press outwards, but the shape of the abutment was intended to give a

constant diameter, while the spring secured an elastic contact. As the shaft revolves, this diametral piston is forced to and fro by the interior surface of the chamber, and with the abutment divides the volume into three portions of continually varying dimensions.

By the revolution of the piston, gas and air are drawn into the chamber through a port at the bottom of the cylinder, and a little later an external flame explodes the mixture, generating a pressure which, acting on the unbalanced area of one blade, causes the fly-wheel shaft to revolve. After thus doing work, the products of combustion escape through an outlet at the top of the chamber. There are two explosions per revolution, but, in common with all engines of its time, there is no compression of the charge before ignition.

The admission of gas and air to the cylinder is controlled by a semi-rotary plug valve, which also shuts off the intermittent igniting flame, the latter being re-lit after the explosion by a permanent light at the side. This valve is driven by a cam on the fly-wheel shaft; the exhaust outlet has no valve, but is shut off periodically by the revolving piston.

It is stated that the engine ran at about 100 revs. per min., gave off ·3 brake H.P., with a gas consumption about the same as that of the Hugon engine.

335. Otto's gas engine. Lent by Messrs. Crossley Bros., 1888. Plate VIII., No. 1. M.1913.

This is a small example of the first silent high-speed gas engine, and was constructed under the patent obtained by Dr. N. A. Otto in 1876. It works on the "Otto," or four-stroke cycle, now almost universally used in gas engines, by which silent working and a great reduction in the gas consumption are simultaneously effected. Although Dr. Otto was the first to construct and introduce practically an engine working in this way, the scheme had been proposed by Mons. A. B. de Rochas in a treatise published in 1862, so that this cycle sometimes bears his name.

The engine is single-acting, and when exerting its full power makes one explosion or working stroke in every four strokes; the first outward stroke draws in a cylinder-full of gas and air, which, in the second or return stroke is compressed into the clearance space left at the back of the cylinder; at the commencement of the second out-stroke this compressed charge is fired, the resulting high pressure driving the piston through this third stroke, and by the crank and shaft transmitting much energy to the fly-wheel. At the completion of this stroke the exhaust valve is opened, and remains open during the return or fourth stroke, during which the products of combustion are delivered by the exhaust pipe into the atmosphere; the next outward stroke commences a fresh cycle by taking in a new charge. By compressing the charge before firing it, nearly double the amount of air that otherwise would be permissible can be present in the mixture without preventing its being ignited, this additional cushion moderating the violence of the explosion and giving a more sustained pressure during the working stroke.

The cylinder is water-jacketed, and the gas and air are admitted by a slide-valve at the back, which serves also as an igniting valve by carrying a pocket of flame from an external light to a small port; the exhaust valve is of the drop type, and is placed at the side of the cylinder. Both valves are actuated by a shaft driven by gearing at one-half the speed of the crank-shaft. In later examples slide valves have been displaced by those of the drop type, and the ignition is generally performed by a

porcelain tube heated to redness by an external gas jet. The speed of the engine is regulated by a centrifugal governor, which, when the normal speed is exceeded, prevents the admission of gas, so that no explosions take place till the speed has fallen to the prescribed limit.

At the trial by the Society of Arts in 1888, one of these engines, with a cylinder 9·5 in. diam. by 18 in. stroke, ran at 160 revs. per min., and developed 17·5 I.H.P., of which 14·7 was available on the brake, so that the mechanical efficiency was 86 per cent.; the gas consumption was 24·1 cub. ft. per brake H.P. In 1894, by some improvements and still higher compression, the consumption of gas per brake H.P. had been reduced to 16·5 cub. ft.

336. Atkinson's "Differential" gas engine. Lent by the British Gas Engine and Engineering Co., 1888. M.1883.

This is the original engine patented by Mr. Atkinson in 1885, and exhibited at the Inventions Exhibition. By its action the charge is compressed before ignition, an impulse is obtained every revolution, and expansion is carried out to such an extent that the volume of the discharged gases is about double the initial volume of the charge; also, the waste products are almost completely expelled.

In the single cylinder are two pistons, connected with a common crank-pin by bell-cranks and links. At the commencement of the cycle the pistons almost meet, the left-hand one then moves rapidly outwards, drawing in the charge of gas and air, and on reversal compresses it while, owing to the position of the links, the other piston has barely moved. The left-hand piston at the limit of its travel uncovers a port leading to an external hot tube by which the charge is ignited. The crank is now in such a position that the right-hand piston moves rapidly and completes a long stroke, after which the products of combustion are expelled by the two pistons approaching each other till they nearly meet. This action is clearly represented in the attached diagram model (scale 1 : 8). The actual engine shown is of 1 H.P.

337. Diagram model of Atkinson's "Cycle" gas engine (working). (Scale 1 : 4.) Made in the Museum, 1894. M.2565.

This represents an engine introduced by Mr. J. Atkinson in 1886 as an improved machine for obtaining the same action as was secured in his "differential" engine, No. 336.

The engine has one cylinder, and is single-acting, but by a peculiar arrangement of links two double strokes are made for one revolution of the fly-wheel, and as it is a compression engine, this gives one impulse per revolution. The connecting-rod from the piston is attached to a crank arm, which only vibrates through an angle of 90 deg., while from the pin of this crank another connecting-rod passes upward to the crank-pin of the fly-wheel shaft; this connecting-rod is triangular, having three pin joints. The result of this arrangement of mechanism is that the explosion stroke is about twice the length of the compression one, so that a considerable degree of useful expansion, with corresponding economy, is secured. The cylinder is water-jacketed, and tube ignition is employed.

The engine represented was of 6 H.P., with a cylinder 9·5 in. diam. and a crank throw of 12·87 in., which, running at 131 revs. per min., exerted 9·5 brake H.P., with a gas consumption of 22·6 cub. ft. per brake H.P. hour.

338. Petroleum engine. Lent by J. H. Knight, Esq., 1891. **M.2373.**

This engine resembles a horizontal gas engine, but vapourised petroleum instead of gas is used in forming the explosive mixture. The petroleum oil is vapourised in a chamber at the back of the working or combustion cylinder, the temperature maintained by the cylinder being sufficient for this purpose; but when starting cold a special paraffin lamp situated under the chamber is lighted, and in about a quarter of an hour heats the vapourising chamber to the requisite temperature for starting, when it may be extinguished.

The engine is single acting and has a cycle of six strokes, two being added for scavenging. The charge is ignited by a wire helix mounted on the slide valve. The helix is maintained white hot by a mineral oil blow-pipe worked from a bellows at the side of the engine, and at the right instant the valve carries the helix from the flame and slides it over a cylinder port, thus placing it in the already compressed and explosive charge. The governor acts by regulating the quantity of oil fed into the vapourising chamber by the small pump which forces it from the reservoir in the engine bed.

The motor shown is of ·5 H.P., and it is stated that 1 lb. of petroleum consumed in it does the same amount of work as 2 to 2·5 lbs. of coal in a steam plant of similar power.

339. Petrol motor with magneto-electric ignition (working). Made by the Simms Manufacturing Co., Ltd., 1905. Plate VIII., No. 2. **M.3410.**

This is a high-speed internal combustion engine working on the Otto four-stroke cycle (*see* No. 335), using petrol as fuel; it is designed for use on motor cars and launches, or for industrial purposes.

The engine has one single-acting cylinder 95 mm. (3·74 in.) diam. by 110 mm. (4·33 in.) stroke, and develops 5 H.P. when running at its normal speed of 1,200 revs. per min. but may develop 6 H.P. when accelerated. The cylinder is cast in one piece with its head, valve chamber, and water jacket. It is mounted vertically over a closed aluminium chamber supporting the crank-shaft in bearings at each end, and carrying at one side a cam shaft driven by toothed wheels, at half the speed of the crank shaft. The elongated piston is packed with three spring rings, and the connecting-rod is attached by a pin passing through it. The crank-shaft is balanced and carries on one end a heavy fly-wheel whose coned interior forms one member of a friction clutch through which the power is transmitted. Wings formed on the crank chamber support the engine from a suitable frame-work. The valve chamber is divided by a horizontal partition in which are formed two seats for the inlet and exhaust valves, the port leading to the cylinder being above it. The valves are of steel and their spindles extend downward through the bottom of the chamber to meet the cam rods which operate them, springs being provided to return the

valves to their seats. Below the valves the chamber is divided vertically, one side being the inlet and the other the exhaust. The valves are easily removed after taking out a screwed plug above them and a cotter in the spindle.

Petroleum spirit, petrol, is used in preference to the heavier and cheaper oils chiefly on account of its easy vaporisation, certainty of ignition, and small residue; it is a mixture of light hydro-carbons obtained by the distillation of crude petroleum and has a sp. gr. of ·68 to ·7. The explosive mixture, consisting of 1 vol. of petrol vapour and 17–20 vols. of air, is prepared in a float feed carburetter of the Daimler-Maybach type. This consists of a chamber attached to the inlet pipe of the engine having in the centre a fine vertical nozzle; the nozzle communicates with a larger chamber containing a float which actuates, by weighted levers, a needle valve so as to keep the petrol at a constant height in the nozzle. During the suction stroke of the piston air is drawn in round the nozzle through adjustable openings and draws off the petrol, which is vaporised and mixed with it in a fairly constant proportion. The petrol enters at the bottom of the float chamber through a gauze strainer. The ignition of the mixture is performed by a low tension spark, the current being supplied by a magneto-electric machine of the form patented by Messrs. R. Bosch and F. R. Simms in 1897–98. This consists of a permanent compound horseshoe magnet fixed vertically on a non-magnetic bedplate and having an armature of H section fixed between its poles; one end of the armature winding is attached to an insulated terminal and the other to the core itself, thus being in metallic connection with the cylinder. In the air gap between the armature and poles an iron shield is placed, consisting of two segments, connected at the ends and provided with pivots; this is oscillated by a rod from a crank-pin in the sparking cam fixed to the half speed shaft, thus varying the magnetic flux through the armature coil and generating a current. The spark is produced by a contact breaker consisting of an insulated pin projecting into the combustion chamber and a spindle carrying an interrupter arm which is normally held in contact with the pin by a spring acting on an external lever, but is knocked off by a tappet-rod raised by the cam and returned by a spring. The circuit is completed through the cylinder and casing. The time of ignition can be varied by a lever which pulls over the lower end of the tappet-rod. The speed of the engine is regulated by a centrifugal governor which operates a butterfly valve placed in the inlet pipe, so throttling the mixture and reducing the compression. When extra power is required the governor may be put out of action and the engine allowed to race.

The cylinder and valve box are cooled by a water jacket surrounding them. Lubricant is supplied to the crank-chamber to be distributed by the splashing of the crank. The engine is started by a movable winch handle engaging with a pin on the shaft, a cock on the cylinder head being opened to reduce the compression, which is normally 70 lbs. per sq. in. The total weight of the motor is 186 lbs. The petrol consumption of such motors varies from ·8 to 1·6 pints per brake H.P. hour.

MOTORS.

OTHER THAN HEAT ENGINES.

Animal Power.—Although as a motor, an animal is possibly a heat engine, its cycle is complex, and so far outside the sphere of the engineer, that in this instance the reference is only to the mechanisms by which the work developed is transformed into forms most convenient for industrial purposes. Before the invention of the steam engine the work of the manufacturing world was all performed by wind, water, or animal power, the latter probably supplying by far the greatest quantity, but the total demand was then very small; that it has since so greatly increased is owing to the cheapening of the cost of power, and the vastly greater supply available, by the conversion of the energy of coal into mechanical work.

A man by rowing, or by walking up a ladder or a treadmill can exert his greatest power, but for ordinary work turning a winch handle is the more convenient method of applying his energy, although considerably less perfect. On a winch handle a man can perform, for an eight-hours day, work at the rate of from 2,200 to 3,300 ft. lbs. per min., or from ·06 to ·1 of a H.P. For a minute or two he can work at about eight times this rate, after which he must rest for a considerable period.

A horse can perform most work when pulling horizontally at a speed of about 2·5 miles per hour, when for an eight-hours day he will do work at the rate of from 22,000 to 33,000 ft. lbs. per min. For driving machinery, however, a horse gear or gin is usually necessary, and on the circular track the work obtainable is only from 16,000 to 26,000 ft. lbs. per min. An ox in a gin does about 16,000 ft. lbs. per min., but must travel at about one-half the speed of the horse. A donkey will exert about 5,000 ft. lbs. per min., but his speed of maximum efficiency is greater than that of the ox.

Windmills.—The power of the wind is probably the form of energy that was earliest utilised by man. At first, doubtless it was only used as a means of propelling vessels, but its adaptation to drive a wheel for industrial purposes is of very ancient date, and until the introduction of the steam engine was of the greatest importance—the only rival being the water-wheel, which, however, through its dependence upon a flowing stream, was of far less general application than the more irregular windmill. The result is that we find, in this country, for instance, where the districts are hilly and consequently water energy is available, but few remains of windmills, while on the flat eastern coast, as also in the low-lying districts of the Netherlands, large numbers of them are working. It would appear that from the 12th century windmills came into general use in England for corn grinding, being introduced by the Dutch engineers. They usually had four arms of about 30 ft. radius, but five or more arms were afterwards

employed—the advantage of the five arms being that in rough weather only two would be exposed to the full force of the gale, while three would be below and have a steadying action. The early machines were adjusted to turn into the wind by manual power, but this was afterwards superseded by various automatic devices; the larger windmills now usually have a small windmill attached which by a stationary spur ring and bevel gearing turns the mill into the wind.

The ordinary four-armed windmill with arms from 30 to 40 ft. radius is considered to develop an average of 8 H.P. Such a mill for corn grinding has usually a bevel gear connection with a vertical shaft carrying a large spur wheel. Round this wheel are four pinions, three of which each carry a mill stone about 4 ft. diam., and the remaining pinion drives the cleaning and dressing machinery. Each pair of stones requires about 4 H.P., runs at 120 revs. per min., and grinds four or five bushels per hour. The number of stones in use depends upon the velocity of the wind, as the power of the mill when running varies from 4 to possibly 20 H.P. In recent years a much smaller and lighter form of mill has been largely adopted for pumping and other light work, and where the situation is favourable windmills are particularly economical for raising water, since the intermittent and irregular action is of no importance. These wheels, which are commonly from 6 ft. to 30 ft. diam., are known as solid wheels, because they present a complete disc to the wind—the disc being made up of a large number of narrow vanes. The great number of vanes so obtainable results in the power given off being much greater than the size of the wheel would suggest, and as they run at a considerable speed, a crank on the end of the wheel spindle revolves at a sufficient rate to be connected directly with the pump to be worked. Various devices have been adopted to make such mills self-regulating or to render them capable of withstanding a gale without attention. In one arrangement the vanes of the wheel open automatically under excessive wind pressure; in another the wheel turns itself edgeways to the wind; while in a third it closes itself somewhat after the fashion of an umbrella.

Many attempts have been made to construct a windmill that will work on a vertical axis, as such a machine would possess many advantages from its being independent of the direction of the wind; but up to the present it has not been found possible so to arrange the wheel as to make a better machine than that of the disc type.

Water Wheels.—The energy in flowing water is an obvious source of power, and the Persian wheel, which lifts water in small buckets attached to a water-wheel, is perhaps the most ancient machine of this class. Where there is a high fall of water, it is usual to employ an overshot wheel, so as to avoid the construction of a very large wheel, such as would be required if a breast wheel were used, that is, one receiving the water at about the level of the axis. If the water comes on rather above the axis, it is commonly

called a 10 o'clock wheel, and wheels of this type have been made up to 61 ft. diam. In these cases, the exact form of the buckets, or floats that form the buckets, is very important, as they must be open enough to receive the water quickly, and yet so much curved as not to lose it too soon, as the buckets approach the lower position. One other form is the undershot wheel, which is generally used where the fall is small. In certain situations where water is plentiful, and there is a fall of 10 or 12 ft., the water is allowed to flow freely down an inclined surface to a small undershot water-wheel, which it thus drives at a high velocity such as is required for driving a circular saw mill.

Turbines.—The first turbine was probably that introduced by Fourneyron in 1827, but since then the improvements in this type of water motor have led to the adoption of turbines in many situations where water-wheels could equally conveniently be used as well as in those where, from the high fall available, the construction of an efficient water-wheel would be impossible.

In a turbine the water is received under pressure into a casing from which it escapes in a number of tangential jets upon the vanes of a wheel; these vanes are so curved that the water does not strike them, but in sliding along their faces has its direction of motion quietly altered, so exerting a pressure on the vanes that drives the wheel. The speed of the wheel is so arranged that the water leaving it has a backward velocity equal to the forward velocity of the wheel, so that the discharged water leaves the turbine dead, all its initial energy being absorbed by the wheel. If the water enters the wheel at its inner periphery and is delivered at its outer, the machine is called an outward-flow turbine (*see* No. 353), while the reverse of this is an inward-flow turbine (*see* No. 355). If the water enters the wheel on one face and is delivered from the other, the flow is axial, while combinations of these courses characterise the mixed-flow turbines (*see* No. 356). Where the head is high, and consequently the quantity of water required to give off a certain power small, a single jet may be sufficient and the turbine then reduces to the simple but very efficient machine known as a Pelton wheel (*see* No. 351).

Pressure turbines are those in which the water in the wheel is still under pressure; such machines act partially or wholly by the reaction of the streams discharged from the wheel. If working entirely by reaction, "Barker's mill" represents the arrangement, and only a moderate efficiency is possible, the machine not being a true turbine owing to the rotary motion left in the discharged water. When the pressure in the wheel is one half of the initial pressure, the rotation of the wheel is caused by the action of the streams entering under one half of the total head, and the reaction of those streams on leaving the wheel under the other half of the head. Such turbines give a high efficiency and have a great advantage in being able to work submerged.

Horse Gears.

340. Model of horse gear. (Scale 1 : 8.) Lent by Messrs. J. L. Larkworthy and Co., 1891. M.2385.

This shows a very general form of machine for applying the power of a horse to the driving of light machinery, such as chaff-cutters, small pumps, etc.; but although larger gears are made to transmit the power of two or four horses, they are not much used in this country when the power required approaches that of a small steam engine.

The machine has a pole attached to the vertical axis of a bevel wheel of 103 teeth, gearing into a bevel pinion of twelve teeth whose rotation is transmitted by a shaft coupled by universal joints to multiplying spur gear placed outside the circular horse track. The multiplying gear consists of a spur wheel of seventy-six teeth driving a pinion of seventeen teeth, to the shaft of which a pulley is attached for further transmitting the power by belting. The horse in going once round the track causes the pulley to make 38·3 revolutions, and when walking 2·5 miles per hour, in a path 25 ft. in diam., drives the pulley at 108 revs. per min.

341. Horse gear. Lent by Messrs. J. Crowley and Co., 1888. M.1958.

This is a small and compact form of gear patented in 1879 and intended for use with a pony. The slow speed of the vertical shaft turned by the animal is multiplied 30·2 times, so as to give higher speed to the horizontal shaft from which machinery is to be driven. To the bracket that holds the pole is attached a short horizontal shaft, carrying a bevel wheel of thirty-one teeth and a bevel pinion of sixteen teeth. The pinion gears into a horizontal bevel ring that is stationary, and forms part of the framing. The bevel wheel gears with a bevel pinion of twenty-two teeth on a vertical axis in the centre, and this pinion carries with it a bevel wheel of sixty teeth that gears with a pinion of sixteen teeth on the high-speed shaft. From this shaft the motion is transmitted through two Hooke's joints to the external driving pulley, a pawl gear preventing accidental rotation in the wrong direction.

342. Model of inclined-plane horse-gear. (Scale 1 : 5.) Made by Mons. J. Digeon, 1892. M.2428.

A wooden platform, constructed as an endless belt, is supported on rollers, and at each extremity passes round a polygonal pulley. It is inclined at an angle of 13 deg., giving a rise of 1 in 4·5. The horse stands on the sloping platform, which is set in motion by the component of the horse's weight acting parallel to the platform, less the frictional losses, which are considerable. The horse's head is haltered to a bar in front, so that he is compelled to walk as the platform recedes (*see* No. 134).

Windmills.

343. Drawings of windmills. (Scales 1 : 32 and 1 : 24.) Contributed by Hyde Clarke, Esq., 1866. M.1010–1.

The sectional drawing, dated 1802, shows a four-armed windmill, driving two pairs of mill-stones, a dressing machine and a sack hoist.

Beneath the mill is a nearly horizontal water-wheel, connected by bevel gear with the main shaft, and probably provided as an alternative source of power. The cap of the mill is carried on friction wheels and is automatically slewed by a small wind wheel whose plane is at right angles to that of the large arms.

The regulating arrangement of this mill was patented in 1789 by Stephen Hooper, of Margate, and forms an early instance of the application of the centrifugal governor. Each sail is made up of small units wound on separate rollers, and when the velocity of the windmill increases, centrifugal action causes these elements to be rolled up against the pull of a weighted spiral drum or fusee within the mill. Hooper also described a conical pendulum governor which was to feed more corn into the stones when the speed increased.

The sectional elevation, dated 1804, shows the construction of a four-armed windmill driving three vertical rolls, probably for squeezing the juice from sugar-cane. The cap of the mill is carried on friction wheels, and is turned by a large hand-wheel provided with a worm that gears into a spur ring secured to the top of the tower; by these means the mill can be adjusted as the direction of the wind alters.

344. Model of pumping windmill. (Scale 1 : 12.) Lent by Messrs. J. Warner and Sons, 1888. M.1951.

This windmill, patented in 1868 by Mr. F. Warner, is arranged for driving a small pump. The sails can yield when the pressure of the wind increases, and thus automatically adjust themselves to suit the force of the wind. Each long radial sail turns upon an axis on its front edge, so that it can vary the angle which it presents to the wind. A balance-weight suspended from a lever behind holds the sails at their best angle when the wind is light; when the wind increases in force, the sails yield, lifting the balance-weight.

345. Model of a pumping windmill. (Scale 1 : 12.) Lent by Messrs. T. McKenzie and Sons, 1888. M.1950.

This form of self-regulating windmill was introduced by Mr. D. Halliday in 1877. Its vanes are arranged in groups forming sectors of the complete disc; each sector, as the speed increases, turns on its tangential axis, so as to reduce the area it presents to the wind. A weighted lever is provided for adjusting the speed or stopping the mill.

Water-wheels.

346. Model of a water-wheel, by James Watt. Watt Collection, 1876. M.1813.

This is an overshot wheel with the usual timber shaft, but on one side the wheel is provided with a toothed ring from which the power can be taken off at once at the highest speed, without transmission through the main gudgeon. The teeth are external to the rim, but in later wheels internal teeth were adopted, and this formed a still further improvement.

347. Models of wooden water-wheels made at Freiberg, Germany. (Scale 1 : 10.) M.2753.

These show various types of timber water-wheels, together with details of the joints employed in their construction.

In the float wheel the radial blades dip into a running stream, and utilise only a small proportion of the energy of the water. The other three models are forms of overshot water-wheel; one has a closed sole plate, and so is unable to fill or empty its buckets rapidly through the lack of ventilation; the other two represent wheels with ventilated buckets.

348. Models of water-wheels for mine drainage. (Scales 1 : 12. and 1 : 24.) Received 1851. M.1417-8.

The larger model shows a portion of a breast wheel erected at the Devon Great Consolidated Copper Mines near Tavistock, to work the pumps in three shafts; the wheel is driven by the river Tamar and the connection with the pumps, which are nearly half a mile away, is made by iron rods 3·25 in. diam. carried on guide rollers. The excess weight of the spear rods in the shaft is partially balanced by bobs placed near the wheel so that the transmission bars are always in tension. The wheel is 40 ft. diam. by 12 ft. face, the oak axle is 5 ft. diam., with cast iron journals 15 in. diam., and at each end has a crank giving a stroke of 42 or 48 in. as required. The wheel is of the high breast type, with the water laid on at 20 deg. from the summit, and its normal speed is 4 revs. per min. Each of its 112 buckets is formed of two deal boards secured to flanges on the cast iron shroudings; the backing of the buckets, or the sole of the wheel, is also formed of deal boards.

The smaller model shows a similar arrangement adopted at the Wheal Friendship, also in Devonshire. The wheel is 50 ft. diam. by 10 ft. face and has 180 buckets built of wrought iron; the axle is a hollow iron casting with flanged ends, but the arms are of wood. The power is transmitted to the mine pumps by wrought iron rods, and balance bobs are used, but these are arranged in pits behind the wheel.

349. Model of a breast water-wheel. (Scale 1 : 12.) Lent by Messrs. Whitmore and Binyon, 1888. M.2254.

In this type of wheel the water is led to it at about the level of the axis, and then allowed to pass through sluices, to fill the buckets. The wheel is turned by the weight of the water in the buckets, descending through about one quarter of a circle. The buckets are shaped with a view to retain as much as possible of the water during the descent.

350. Model of Poncelet's water-wheel. (Scale 1 : 10.) Made by MM. Regnard Frères, 1891. M.2400.

This shows a most efficient form of undershot water-wheel; its chief feature is in the shape of the floats which are curved backward in such a manner that the water shall enter the wheel without avoidable shock, and be discharged with but little remaining forward velocity.

The water enters through an inclined sluice nearly tangential to the wheel, with the full velocity due to the head, and acts on the curved

floats as it ascends into the buckets, and also as it flows down again under the action of gravity, being finally discharged with a backward velocity relatively to the wheel. The maximum efficiency of 65 per cent. is not obtainable if the fall exceeds 4 ft., and is in all cases less than that of a modern turbine, but the machine is somewhat simpler. The regulation is effected by a gate at the entrance of the sluice, so that the initial velocity is always that due to the head, thus fairly maintaining the efficiency while lightly loaded.

Turbines.

351. Model of a Pelton or "Hurdy Gurdy" water-wheel (working). (Scale 1 : 4.) Lent by the Sandycroft Foundry and Engine Works Co., 1890. Plate VIII., No. 3. M.2352.

This is a form of impulse turbine much used in mining districts and other situations in which considerable head is available, as its high speed and great power render it a most convenient motor, while its extreme simplicity minimises the risk of failure.

The early form of the machine consisted of a wheel having radial floats or paddles projecting from it, upon which a rapid stream of water was directed by a shoot; reversal or stoppage were both effected by moving the shoot—the supply of water in such cases generally far exceeding the power requirements. Wheels with concave vanes (as in the Italian amalgamating mill) were in use about the year 1800, and Poncelet in 1827 proved their superiority over those with flat vanes, but it was considerably later that in the mining districts of California the practical development of this important form of turbine was chiefly effected. The original "miner's wheels" there employed were shrouded and had vanes made as triangular prisms; they had an efficiency of about 40 per cent., but were subsequently improved by the adoption of cup-shaped vanes. In 1874, however, Mr. J. Moore improved these vanes by forming them with a central wedge-shaped ridge which split the jet, while in 1878 Mr. L. A. Pelton independently arrived at this double construction of cup, and to him the commercial introduction and development of the Pelton wheel is chiefly due.

The model has a central wheel of cast iron, to the rim of which are secured twenty-eight double buckets of gun metal 2·3 in. wide, the overall diameter of the revolving parts being 20 in. The shaft is carried in three bearings, near the central one of which a screen or partition would be fitted to prevent water splashing upon the belt pulley by which the power obtained is transmitted. The supply water, which is usually brought through light pipes of sheet steel, is, after passing through a sluice valve, led by a conical pipe to a removable discharge nozzle, so that by changing the nozzle the load on the wheel may be greatly altered without seriously reducing the efficiency of the motor.

Each bucket or cup consists of two semi-cylindrical portions, uniting in a central ridge which divides the entering water jet so that each half slides round the inside of its cup and has its motion reversed before escaping at the opposite edge; by running the wheel at a circumferential speed slightly less than half the velocity with which the water issues from the nozzle the water is discharged from the cups, dead, its energy being completely transferred to the wheel. To facilitate the escape of the dead water from the wheel, the buckets are given

a forward inclination; the wheel must, however, in all cases, be above the level of the tail race; under suitable conditions an efficiency of over 80 per cent. is easily obtained with such a machine.

352. Encased Pelton wheel. Presented by P. Pitman, Esq., 1903. M.3296.

This is a small example of an arrangement of impulse turbine in which, by enclosing the wheel, the machine is adapted for use as a motor within a building; the pressure water may be obtained from the domestic mains or other supply, while the used water is led away by a pipe from the bottom of the case.

The centre of the wheel is a cast iron disc to which are riveted twenty double-cupped buckets of bronze, which are given a backward slope to facilitate the discharge of the used water; the shaft of the wheel is carried in external bearings secured to the sides of the casing, and has a pulley attached by which the power given off is transmitted by a belt. One side of the casing is removable so as to facilitate examination of the wheel. The supply water is delivered as a horizontal jet near the bottom of the wheel, while somewhat higher up in the case on the opposite side is a fixed blade, just clearing the buckets so as to prevent used water from being carried round and thereby absorbing power by falling on the wheel. The speed is adjusted by a throughway sluice valve on the supply pipe, but to permit of economical working at much below the full power two extra nozzles of less area than the standard one are provided and arranged for attachment by the removal of a box nut.

The wheel shown is intended to run at 1,300 revs. per min. with a supply pressure of 90 lbs. per sq. in., when it gives off ·25 H.P.; at a lower pressure the speed and power are less. Similar wheels have been worked at pressures of from 1 to 1,000 lbs. per sq. in.

353. Model of Fourneyron's turbine. (Scale 1 : 4.) Made by T. B. Jordan, Esq., 1842. Plate VIII., No. 4. M.2748.

This represents an outward flow turbine erected in 1837, at St. Blazien, Baden. It was constructed by Mons. Fourneyron, who is considered to have introduced the first true turbine in 1827, after having spent four years in experimenting.

The machine consists of a vertical cylindrical chamber with a side inlet for the water, and a central pipe below through which the water passes to an annular outlet at the base of the pipe. This outlet is fitted with thirty guide blades which direct the water in a tangential course as it escapes. Surrounding this passage is a wheel, keyed to a vertical shaft, and provided with vanes between which the water flows as it passes from the inner to the outer circumference, where it is finally discharged. A full-sized model of a wheel 2 ft. diam. is seen below.

The toe of the shaft is carried in a special bearing, having oil supplied under pressure, and the power given off by the shaft is transmitted by bevel gear at the upper end. The central pipe containing the guides is carried by three screwed rods connected above by gearing, by which the pipe can be accurately raised, so as to contract the supply passage into the wheel if less than full power is required. The water under pressure is discharged in a tangential direction from the fixed guides,

and on passing between the vanes of the enclosing wheel has its direction of motion gradually changed until the energy of the water has been transferred to the wheel, when the water is discharged at the outer rim, dead.

When the water attains its full velocity due to the total head before it leaves the guides, the wheel is of the impulse type, and should be above the level of the tail race; when, as is usually the case in the Fourneyron turbine, the water in the wheel is also under some pressure, a portion of the power of the wheel is derived from the reaction of the jets leaving it, and the wheel, which is known as a reaction wheel, must be arranged to work under water, or drowned.

354. Schiele turbines. Presented by the North Moor Foundry Co., 1863. M.941.

These are small examples of the mixed flow type. The water, having a pressure due to the head, is introduced through a pipe to the spiral outer casing, through which it passes to a series of inclined inlets in an inner casing; passing in through these inlets in a spiral direction, it impinges upon the curved and inclined vanes of the revolving drum, splits into two currents, and passes out at the sides, giving rotation to the shaft. The double construction of the wheels avoids the heavy end thrust that would otherwise result from the axial delivery of the used water.

355. Model of a vortex turbine. (Scale 1 : 6.) Lent by Messrs. G. Gilkes and Co., 1888. M.1919.

This is a working model of an inward-flow turbine of the type patented in 1850 by Prof. James Thomson, the result of whose investigations of the laws of the free vortex have been applied in the design.

It consists of a large casing into which the water enters and from which it escapes axially by two discharge pipes. Fixed in the casing are spiral blades or vanes, which give a spiral direction to the water as it approaches and impinges upon the curved vanes of the drum, to which it imparts rotation. The guide blades are capable of simultaneous adjustment from the outside of the casing, and in this way the supply orifices are reduced to suit the work to be done, and the efficiency of the machine maintained when working at partial loads.

This turbine would use 600 cub. ft. of water per min. with a fall of 25·5 ft., and would give about 22 H.P. at 75 per cent. efficiency; it would make about 250 revs. per min. If the model itself is worked with water it will make about 560 revs. per min., the passages through which the water finds its way to the wheel being properly proportioned for this speed. By having the delivery pipe ends under water, the full power of the "suction head" is utilised, so that these machines can be placed more than 20 ft. above the level of the tail water without loss of energy. When, however, these turbines are intended to work drowned, they are usually arranged to work on a vertical axis.

Photographs and particulars of actual turbines are given.

356. Vertical turbine. Lent by S. Howes, Ltd., 1899. M.3047.

This small example of the "Little Giant" double turbine belongs to the mixed-flow construction, so generally adopted in America. In

the machine shown, moreover, the case and wheel are each divided by horizontal diaphragms, so that the upper and lower portions form complete machines capable of being worked independently; a vertical sluice at the entrance of the spiral supply chamber when half open only admits water to the lower section, thus maintaining the same efficiency on half as on full load.

The turbine is designed to work drowned, the level of the fall water being such that the wheel when running is just submerged, although a rise in the tail race does not interfere with the working, except in so far as the head is thereby diminished. The bottom step, or "toe-bearing," consists of a lignum-vitæ pin working in an inverted cup formed in the lower end of the shaft, while the upper bearing is in three lignum-vitæ bushed pieces, separately adjustable.

The example is a turbine with double wheels 6 in. diam., and is intended to exert 10 H.P. at 1,063 revs. per min. with 152 cub. ft. of water under a head of 44 ft.; under other heads, energy proportional to the 3/2th power of the head is obtained, the efficiency being practically constant, but the quantity of water passed diminishing with a reduced head. For 1,000 H.P. on a 41 ft. fall the diameter of the turbine employed is 44 in., and it runs at 160 revs. per min.

This form of turbine is also made with its axis horizontal, and enclosed in a case fitted with suction pipes so that it can be arranged as much as 20 ft. above the level of the tail race.

WATER AND AIR PRESSURE MOTORS.

357. Water motor with oscillating cylinder (working). Lent by Messrs. W. H. Bailey and Co., 1894. M.2566.

This is a small example of Haag's high-pressure water motor, for pressures up to 300 lbs. per sq. in. These motors are frequently used in mine workings, the water for driving being obtained from the delivery pipe of the main pumping engine, and the motor discharging its exhaust water into the mine sump.

The cylinder of the engine oscillates on two hollow trunnions, closed at the outer ends, the hollow spaces within each trunnion being divided into two compartments, one of which on each side communicates with either end of the cylinder. Two slots cut longitudinally in the trunnion serve for ports for admission and exhaust of the water; one slot giving admission to each end of the cylinder. In the lower part of each bearing there are three ports, a wide one in the middle leading to the exhaust pipe, and a narrower one on each side of this communicating with the supply pipe. The oscillation of the cylinder causes the ports in the trunnions to slide over those in the bearings, so opening up each end of the cylinder to exhaust or pressure alternately, just as in the case of an ordinary slide valve. The supply and exhaust pipes are each fitted with an air vessel to prevent shocks in the pipes.

This motor has a cylinder 2·5 in. diam. by 4 in. stroke, and when making 100 revs. per min. under a pressure of 150 lbs. gives off 1 brake H.P. Larger sizes are made up to those having 9 in. cylinders, which running at 50 revs. per min. exert 24 brake H.P. under 150 lbs. pressure. These engines will also work with steam, but are then fitted with a governor and variable expansion gear.

358. Water pressure motor (working). Lent by the Glenfield Co., 1896. M.2965.

This is an example of Wilson's water motor for pressures up to 200 lbs. per sq. in.; such motors are intended for driving small quick running machinery, dental drills, ventilator fans, etc.

The two cylinders are double acting, fixed with their axes at right angles to each other and working by connecting-rods a crank-pin common to both. One eccentric actuates both valves which are of the solid piston type. To prevent shock at the reversal points a small conical seated relief valve is fitted to each water passage opening into the valve chamber, the pressure there keeping them closed under normal conditions. The supply and exhaust passages are cast with the framing connecting the two cylinders.

This motor has cylinders 1·25 in. diam. by 1·5 in. stroke, and when running at 200 revs. per min. under a pressure of 150 lbs. exerts about ·3 brake H.P.

359. Hydraulic motor in section. Made by the Hydraulic Engineering Co., 1888. K.497.

This is a small motor on Brotherhood's system with three single-acting cylinders inclined at 120 deg. to one another, and having trunk pistons with cup-leather packing. The connecting-rods are always under compression and are ball-jointed at the piston end, while at the other extremity they each embrace 90 deg. of the crank-pin. The water is distributed by a rotating disc valve (shown separately in section) which has an opening from the outside for pressure, while the exhaust passes through the spindle; the port face is of lignum-vitæ.

The example has cylinders 1·75 in. diam. by 2·5 in. stroke. It gives 2 brake H.P. at 105 revs. with 7 gallons of water per minute at 750 lbs. pressure, and 2·5 brake H.P. at 87 revs. with 5·75 gallons at 1,050 lbs. pressure.

360. Hydraulic engine. Lent by the Glenfield Co., 1896. M.2965.

This is a small example of a three-cylinder water pressure engine, suitable for pressures up to 1,000 lbs. per sq. in.

The three cylinders are cast together, their axes radiating at 120 deg. to each other, and they are always open at their inner ends to the crank chamber. The pistons are packed with cupped leathers and are hollowed out to receive the spherical ends of the thrust bars by which motion is given to the crank. The pressure is always on the outer end of the piston, so that the thrust bars are in compression and take up their own wear. The water is admitted and exhausted by means of a circular disc valve driven by a stem from the crank-pin and working on a face which in the case of the larger engines is made of lignum-vitæ. Water is admitted at the side of the valve chamber and exhausts by the centre of the valve.

This example has cylinders 1 in. diam. by 1·5 in. stroke, and when running at 250 revs. per min. with 600 lbs. pressure gives off about ·75 brake H.P.

361. Tidal motor. Contributed by Richard Roberts, Esq., 1858. M.182.

This apparatus, patented by Mr. Roberts in 1848, is shown arranged for clock-winding, or doing lighthouse work, by tidal energy.

The machine is erected over a tank or well to which the tide has access; into this hangs a weight and also a float, connected by a chain that passes over a sprocket wheel on the overhead shaft, then round a loose wheel on the framing and back over another sprocket wheel. These wheels are connected with the shaft by ratchet and pawl mechanism, which causes both upward and downward movements of the float chain to rotate the shaft, always in one direction. The power so obtained will cease for a while during the turn of the tide, and therefore, when continuous motion is required, an additional mechanism is added. On the end of the intermittently rotated shaft is a sprocket wheel, and on the shaft to be continuously rotated, which is in line with it, is another sprocket wheel; over the two wheels hangs an endless chain, in the loops of which are two weighted sheaves, one of which is much the heavier, the difference being the driving weight. When the tidal motion is rapid the excess power is stored by lifting the weight, while when the tidal movement stops, this weight gives off its stored energy in descending, and so keeps the driving shaft in motion. The weighted sheaves are connected by a hanging chain which prevents the inequalities in the effort which would otherwise arise from the varying length of chain on the driving side.

362. Compressed air motor. Lent by the International Pneumatic Tool Co., Ltd., 1901. M.3208.

This is a small portable machine for rotating the tools used in drilling, tapping, tube expanding, etc., by the application of mechanical power, so as to reduce the time otherwise necessary in performing such work by hand labour alone.

The sectioned example shown is a piston motor, patented in 1896 by Mr. H. J. Kimmans, in which there are four fixed single-acting cylinders arranged in pairs in two planes at right angles and driving a two-throw crank-shaft having cranks at 180 deg. Two pistons are connected with each crank-pin, so that a fairly uniform turning effort shall be maintained. To reduce the bulk of the machine, the connecting-rod ends are in the form of hinged clips embracing their crank-pin, one being forked and bearing outside the other; the ends also embrace the rods, to which they are secured by screwed sleeves. Each pair of cylinders is provided with a hollow piston valve, sliding in a bush and driven by an eccentric; the valve admits air to each cylinder alternately, through suitable ports in the casing and bush which are so proportioned as to give expansive working; the exhaust takes place along the axis of the valve.

The cylinders and crank-shaft are enclosed in a casing which forms an air chamber, and is provided with a cover through which passes a screwed sleeve, with a star handle, for feeding the drill. The tool holder runs on a ball thrust bearing, and has a conical socket for drills and an externally screwed boss; it is driven from the crank-shaft by spur gearing which reduces the speed in the ratio of 1 : 7.

The cylinders are 2 in. diam., 2 in. stroke, and the brake H.P. exerted

is 1·5, with a consumption of 35 cubic feet of free air per minute. The weight of the motor complete is 35 lbs., the air pressure used is from 70 to 100 lbs. per sq. in., and the maximum duty of the machine is to drill, in metal, holes of 2 in. diameter.

MAGNETO MACHINES, DYNAMOS, TRANSFORMERS, AND SECONDARY BATTERIES.

The discovery of the existence of relationship between electricity and magnetism was first made by Oërsted in 1819, when he found that a magnetic needle was deflected by the passage of an electric current through an adjacent conductor. In 1825 Sturgeon constructed an electro-magnet, and in 1831 Faraday discovered that the motion of a permanent steel magnet in proximity to a coil of wire caused a current to pass through the latter; from this observation he proceeded to construct what became the first magneto-electric machine. It consisted of a copper disc capable of being rotated between the poles of a horse-shoe magnet, and provided with terminals connected with the centre and circumference, respectively, of the disc; he subsequently replaced the permanent magnets by electro-magnets, thus converting the machine into a form of dynamo which, however, was separately excited by a primary battery. Although Faraday contented himself by obtaining weak currents he fully realised that important practical results would certainly follow from the development of his method of generating electricity. In the following year Pixii constructed a machine having a steel horse shoe magnet rotating in front of two bobbins with iron cores, thus obtaining alternating currents which he afterwards, at the suggestion of Ampère, rectified by the addition of a commutator. In 1833 Saxton produced a machine with a stationary magnet and four moving coils, while in 1834 Clarke arranged and constructed what still remains the usual form of medical coil in which, by a peculiarity of the commutator, the physiological effect of the current was increased. In 1841 Woolrich constructed and patented for use in electro-plating a large multipolar machine having twice as many coils as poles, and in the same year Wheatstone produced, for the purpose of securing a fairly steady current, a machine having six compound steel magnets and five armatures, each with a separate commutator. In 1849 Sinsteden, by forming the core of a magneto machine of small iron wires, introduced lamination in the construction of the armature. The shuttle-wound armature of Werner Siemens, invented in 1854, greatly increased the output of the magneto-electric machine, a striking example of which was shown at the 1862 Exhibition. Holmes and others introduced the powerful "Alliance" magneto-machine, which, driven by steam power, has been employed for generating the current used in the arc lamps of lighthouses since 1863.

In 1863-5 Wilde invented and patented the first separately

excited dynamo, the exciting current being derived from a small magneto machine, and by constructing the machines of considerable size and driving them by steam power obtained currents of hitherto unattained magnitude and intensity. In 1866–7 Varley, Siemens, Wheatstone, and Ladd constructed machines with soft iron electro-magnets, self-excited, which were described as "dynamo-electric machines," a term since contracted to "dynamos." In 1867 Wilde introduced, with the object of obviating the high speed necessary with the shuttle form of armature, a machine with several coils arranged round a cylinder; the current from a few of the coils was rectified and used to excite the field magnet, while the main current as given off by the rest of the coils was taken off by ring contacts, the machine being a self-exciting, alternating current dynamo.

Pacinotti had in 1864 invented a ring armature which, although provided with teeth, was wound with coils in series each brought down to a commutator sector, thus obtaining a very uniform current; but the practical introduction of the continuous current machine dates from 1870, when Gramme reinvented the ring and omitted the teeth, thus introducing the present ring armature machine and obtaining a current of any desired degree of uniformity. Von Alteneck in 1873 converted the Siemens shuttle armature upon the same lines, and so introduced the drum arrangement which for many years was about equally popular with the ring type, but owing to its greater mechanical stability is now the most extensively adopted form, at least for two-pole machines of large output. Since then the chief improvements in the dynamo have been in the mechanical construction and scientific proportioning of the parts, whereby it has been rendered quite reliable, and the efficiency has been raised to well over 90 per cent.

Alternators.—Although the commutator was invented so early in the history of electric generators, many of the early magneto machines gave alternating currents, and Wilde had introduced a dynamo of this type in 1867, but it was not till 1877 when public lighting was attempted by the Jablochkoff candle, in which, as the carbons were side by side, it was essential that they should be consumed at equal rates, that much attention was given to the construction of machines giving alternating currents. The subject, however, soon afterwards received a greater stimulus from the scheme of electric distribution introduced by Gaulard and Gibbs, in which, by the introduction of induction coils, alternating currents at high pressure could be economically transformed to pressures suitable for domestic lighting without the use of moving machinery.

For the transmission of electrical energy to considerable distances, high pressures are essential and it was soon seen that the absence of the commutator rendered practicable the use of pressures which with continuous current machines would be almost impossible, while the subsequent lowering of pressures generally necessary was much more convenient and economical by an induction transformer than by the rotary converter or dynamo

motor necessary with continuous currents. The early self-exciting alternators had some of the current generated rectified by a commutator and then sent through the field magnets, but in modern machines the excitation is usually done by a small continuous current dynamo contained in the framing or else separately driven.

The absence of a commutator in an alternator has frequently rendered it most convenient to fix the armature of the machine and revolve the field magnets, the high tension portion thus remaining stationary; owing to the confusion in terms thus arising the stationary portion is now generally called the "stator" and the revolving part the "rotor."

Polyphase Machines.—In long distance transmission of electricity for power or lighting purposes the high potentials possible with alternating current machines rendered the use of such dynamos almost compulsory. For many years, however, the difficulty in starting alternating motors was a defect which seriously checked the spread of the system as, although most motors of this class when once in step with the generator were virtually geared to it, they would not work by the power current until they had been brought from rest to the running speed, by power from some other source. This grave objection has now been removed by the use of two alternating currents, derived from a single generator but differing in phase when applied to the motor. These currents if led through coils covering separate portions of an iron ring cause a continuous rotation of its magnetic poles, similar to that which would result if the ring were revolved in a steady field. Within such a ring a magnetic cylinder, or a drum formed with closed conducting circuits, will revolve, just as if in the field of a powerful rotating magnet. Upon these principles, two and three-phase self-starting silent motors are now constructed, in which the windings are on the stationary frame and the magnet revolves, sometimes without there being any moving contacts, the magnet being excited by induction from fixed coils. By so arranging a generator that it gives two or three-phase currents its output is increased when compared with that as a simple alternator, but its several currents must be separately conveyed although, by cross connection, only three wires are usually necessary.

Secondary Batteries.—The great fluctuations in the demand on an electric light station have caused much labour to be expended in attempting to store energy in such a way that the maximum demand may be partially met by energy stored during periods of light load. There are also innumerable other applications of electricity in which stored energy is of great value, but up to the present the secondary battery or lead cell is the only device in extensive practical use. In it the electric current, while charging, effects a decomposition which at any reasonable period subsequently will produce a corresponding but reversed current as the recomposition takes place, the arrangement thus storing energy chemically and restoring it in the form of electrical energy. The various forms of cell are, however, all developments of Planté's battery

of 1859 as improved by Faure in 1880. Although such arrangements are much more powerful and economical than any form of primary battery they still remain somewhat heavy storers of energy, and are still but seldom adopted in traction. Where they are used to steady the demand on a lighting station, the cells supply about one-fifth of the maximum current; in private installations, however, it is usual to light entirely from the cells, charging them during the daytime.

Magneto-electric Machines.

363. Early magneto-electric machine. Wheatstone Collection, 1884. M.2203.

This machine has a heavy permanent magnet of the horse-shoe form, which is not laminated, and the magnetic field is consequently feeble. Two bobbins with soft iron cores united by a yoke piece can be rotated in front of the poles by means of spur gearing, and the currents induced in the armature windings are rectified and collected by a simple commutator.

364. Magneto-electric machine by Wheatstone, 1840. Wheatstone Collection, 1884. M.2202.

In this machine the permanent magnet, which is built up of five bars, is arranged horizontally, with an armature consisting of two coils on iron cores, capable of rotation below the magnet and round a vertical axis. It is driven by spur gearing which is arranged outside the case containing the machine. The commutator is on the armature spindle, and the current is brought to outside terminals.

365. Magneto-electric machine by Wheatstone, 1840. Wheatstone Collection, 1884. M.2201.

This machine is similar to the preceding one, upon which it is an improvement mechanically. Here the bobbins rotate above the horizontal magnet, and the speed is greater, the ratio of the gearing being 12 to 1. This is the form of machine that Wheatstone afterwards adopted in his A B C telegraph instrument.

366. Little's magneto-electric machine. Lent by H.M. Postmaster General, 1879. M.2221.

This machine was made by Mr. G. Little in 1852, and has a permanent horse-shoe magnet built up of twelve plates, with the poles upward and clamped together with substantial pole pieces. The armature consists of six coils with wrought iron cores, carried by two zinc discs fixed to the horizontal axis which is driven by a band. The armature is at such a height that only two coils are between the poles at any instant, and a six-segment commutator rectifies the current, but this detail is now incomplete.

367. Magneto-electric machine. Wheatstone Collection, 1884. M.2200.

This machine has six compound permanent steel magnets, arranged radially in a circle with the armature in the centre, as patented by Sir C. Wheatstone in 1858.

The armature coil is contained in the stationary brass box, from which the terminal wires are led. Above the box and below it are three soft iron radial arms, and through the centre of the coil passes freely a wrought-iron core attached to these arms. The core and its projections are rotated round a vertical axis by a band, and, as the radial magnets are arranged alternately with their north and south poles uppermost, rotation of the core causes an alternating current in the coil, giving three complete alternations per revolution.

368. Electro-magnetic engine. Presented by T. Allan, Esq., 1857. M.160.

This is a form of electro-magnetic engine constructed by Mr. Allan in 1852. Like several other early machines, the conversion of electrical energy into mechanical motion was attempted by imitating the action of the ordinary steam engine, the pressure of steam being replaced by the attraction of an electro-magnet on an armature. Such machines are much inferior in efficiency to modern motors.

The very short distance through which the magnetic attraction acts raised difficulties which were solved in various ways, but in this engine a sufficiently long stroke was obtained by arranging four armatures on one piston rod, each armature acting through one-fourth of the stroke. Each electro-magnet is formed of four coils, and its armature is a circular disc resting loosely on a collar on the piston rod, so that when the armature has reached its magnet the piston rod can continue its motion downward under the action of the armatures of another set. A four-throw crank-shaft with the cranks at 90 deg. is driven continuously by the pull of the four reciprocating rods that carry the armatures, but the up stroke of each set of armatures is performed by the pull of those descending, so resembling single-acting cylinders. Mounted on an arm projecting from the crank-shaft is a disc, which rolls round a circular commutator having sixteen segments and directs the current through the various armature coils at the proper time.

369. Electro-magnetic engine. Presented by D. McCallum, Esq., 1862. M.806.

This motor, constructed by Mr. McCallum, is another attempt to convert electrical energy into mechanical motion by copying the action of a steam engine, but in this case the engine is of the beam type.

Under one end of the beam two electro-magnets are arranged vertically. To lengthen the effective stroke the two armatures are made up of horizontal strips spaced some distance apart and loosely connected at the ends in such a way that the strips can be close together or be separated to a certain extent, the armature thus closing down as it reaches the poles. The connection between the inner armature and the beam is by a slotted link, while the outer armature is mounted on a separate arm, the arrangement being such that the armatures are

acting through different portions of the down stroke. A crank and a short connecting rod convert the oscillations of the beam into rotary motion, and the distribution of the electrical current is controlled by a simple commutator on the fly-wheel shaft.

Dynamos and Electric Motors.

☞ **370.** Wilde's separately excited dynamo. Presented by Dr. Henry Wilde, F.R.S., 1897. Plate VIII., No. 5. M.2969.

In 1863–5 Dr. Wilde invented and patented the first separately excited dynamo. In describing it before the Royal Society in March, 1866, he stated that its action demonstrated that the feeble current from a small magneto-electric machine would by the expenditure of mechanical power produce currents of great strength from a large dynamo.

The larger of the three dynamos then described by Dr. Wilde weighed 4·5 tons, and had an electro-magnet formed of two plates of rolled iron, 48 in. high, 39 in. wide, and 1·5 in. thick, bolted together at the top through a wrought-iron bridge. The magnet was provided with lower pole-pieces, separated by gunmetal blocks, and bored out to just clear a shuttle armature, 10 in. diam. The field-windings consisted of a bundle of thirteen insulated copper wires, each ·125 in. diam. and 4,800 ft. in length, while the armature contained 376 ft. of a similar insulated bundle of wires. This dynamo was excited by the rectified currents from a much smaller one, the electro-magnet of which was excited by the rectified currents from a small magneto-electric machine. The permanent magnets of this machine weighed 6 lbs., and sustained collectively a weight of 60 lbs., but the electro-magnet of the larger dynamo was estimated to have a sustaining power of 20 tons. When driven at 1,500 revs. per min., the current from the larger dynamo fused 15 in. of round iron ·25 in. diam., or 7 ft. of iron wire ·065 in. diam. with an expenditure of about 10 H.P., while the arc light evolved from it was sufficiently powerful to cast the shadows from the flames of gas lamps a quarter of a mile distant, upon the neighbouring walls.

The machine shown, which was for many years in use at an electroplating establishment where it deposited 20 oz. of silver per hour, closely resembles that illustrated in Dr. Wilde's paper of 1866, except that in the early machine the exciter, having permanent magnets, was without any field-windings.

371. Varley's original dynamo. Lent by S. Alfred Varley, Esq., 1887. Plate VIII., No. 6. M.1859.

This machine was devised by Messrs. C. and. S. A. Varley, in 1866, and provisionally protected in December of that year. Its important feature is that the field magnets are of wrought iron, excited by the currents generated, and that the fundamental current is obtained from the residual magnetism in the iron; this magnetism is soon so intensified by the current generated that it attains a strength far greater than is possible with any form of permanent steel magnet.

The dynamo has two horizontal horse-shoe electro-magnets, between which revolves an armature containing two circular bobbins. The armature is enclosed in a fixed brass casing, through which project pole

pieces, each covering about 140 deg. The armature currents are rectified by a simple form of commutator on the shaft, and are then sent round the field coils as in the modern series-wound dynamo.

372. Siemens's original dynamo. Lent by Messrs. Siemens Bros. and Co., 1897. Plate VIII., No. 7. M.3006.

This is the original series-wound dynamo described to the Royal Society by Sir C. W. Siemens in February, 1867.

The two field magnets are of horse-shoe form and wound with insulated copper wire, which gave a total field resistance of probably 5 ohms. The armature is of the Siemens's double T or shuttle type, and appears to have had a resistance of 4 ohms; the commutator, which is very long, is formed on the spindle and the currents are collected by twenty-two pairs of brass fingers acting as brushes; on the other end of the spindle is a pulley for belt driving. The field and armature circuits were coupled in series, and it was then found that most powerful currents could be obtained when driven by power. It was found necessary on starting, however, to put a single cell in the circuit, so as to give a small amount of magnetism which then by the dynamo action would be increased; but, having been once excited in this way, the residual magnetism of the iron was found sufficient to ensure excitation in all subsequent starts.

373. Wheatstone's original dynamo. Wheatstone Collection, 1876. Plate VIII., No. 8. M.2204.

This machine was described to the Royal Society by Sir Charles Wheatstone in February, 1867, and is one of the first self-exciting dynamos, as well as being the first dynamo worked with a shunted field.

The field magnet is in the form of a built-up horse-shoe of wrought iron, with a section of 7 in. by ·5 in., and the field winding consists of two coils, containing 640 ft. of insulated copper wire ·083 in. diam. The armature is the elongated shuttle of Siemens, 8·5 in. long, wound with 80 ft. of similar wire to that on the magnet, and it has two commutators on the spindle. The dynamo is mounted in a wooden framework and provided with a double set of rope multiplying gear, driven by two men working at winch handles; the rope passes several times over the driving pulleys and is returned by a cross-over sheave. When the armature and field circuit were coupled in series the current heated 4 in. of platinum wire ·0067 in. diam. to redness, but by shunting, Wheatstone found that the armature current could be so increased as to render 7 in. of the platinum wire red-hot. He also noticed that the residual magnetism of the soft iron was quite sufficient to ensure starting.

374. Wilde's multipolar dynamo. Presented by Dr. Henry Wilde, F.R.S., 1896. M.2938.

This type of dynamo was patented by Dr. Wilde in March, 1867, and was introduced to obviate the high speeds necessary with the shuttle form of armature. In the original machine there were sixteen armature cores and sixteen field magnets on either side, with 356 lbs. of wire in the field windings, and 28 lbs. in the armature. At 500 revs. per min., the machine would melt 8 ft. of iron wire ·065 in. diam., and at 1,000 revs.

12 ft. of iron wire ·075 in. diam. The dynamo shown is of later date, but in general design closely represents the earlier form.

The machine has an armature formed of two brass discs, between which are six insulated coils, with iron cores extending through the discs. This armature revolves between two sets, each of six electro-magnets that are attached to the end standard; the coils of these magnets are coupled up in series, with their opposite poles alternating with each other. The current from one of the armature coils is rectified by a commutator on the shaft, and then used to maintain the magnetic fields.

On the shaft is a second commutator by which the electricity from the armature coils can be collected either as a continuous or an alternating current. The example shown has an output of 10 ampères at 120 volts when running at 1,300 revs. per min.

375. Ladd's original dynamo. Presented by Mrs. Ladd, 1885. M.1622.

This machine was described to the Royal Society in March, 1867. It is a dynamo with two armatures separately driven; the current from one armature is sent through the field coils of the electro-magnet, while the current from the other is available for general use, and would heat to incandescence 3 in. of platinum wire 0·1 in. diam.

The magnet consists of two bars of soft iron 2·5 in. by ·5 in. section, each 7·5 in. long, and wound round the central portions with 90 ft. of No. 10 copper wire. Between these cores are the pole pieces, within which revolve two Siemens shuttle armatures, each wound with 30 ft. of No. 14 copper wire.

376. Early Gramme dynamo. Lent by Killingworth Hedges, Esq., 1902. Plate IX., No. 1. M.3232.

The continuous current dynamo, with a ring armature, was introduced in 1871 by Mons. Z. T. Gramme; the small example shown, which was made in 1879 by Mr. W. B. Brain in the Forest of Dean, is stated to have been the first Gramme dynamo built in England. The armature is of the elongated ring type and is wound with sixty coils; the magnet windings are in four rectangular coils and the magnetic circuit is through the cast iron forming the framing. The brushes are made of thin copper strip and the terminals are arranged on the top of the machine, where there is a switch provided for short circuiting at starting to insure excitation.

377. Early Siemens dynamo. Made by Messrs. Siemens Bros., 1878. M.3069.

This is a small example of the original commercial form of the drum armature machine, patented in 1873 by Dr. Werner Siemens and F. von Hefner Alteneck. The armature is a development of the Siemens shuttle form of 1856, and gives a nearly continuous current, in a similar way to the Gramme armature invented in 1870, by the use of a closed series of coils provided at regular intervals with connections to a commutator of many segments.

The armature shown consists of a hollow wooden drum, wound circumferentially with soft iron wire, and provided with wooden pegs, by

which a longitudinal winding of insulated copper wire, held in position by brass bands, is separated into groups. The commutator is in twenty-four segments, and, to prevent any break in the circuit due to imperfect contact of the brushes, two pairs of brushes are provided, one brush of each pair being slightly in advance of the other. The magnets are built up of fourteen bars of wrought iron arranged horizontally and connected at their ends by iron distance pieces, but curved in the middle, so as to leave room for the drum. The field windings are in four elongated coils, arranged to give consequent poles, so that the lines of force tend to run vertically through the armature.

The machine shown has been partially sectioned, but in its original state had the armature and field windings in series; its output was about 20 ampères at 50 volts.

378. Gramme's alternating current dynamo, with exciter. Received 1900. M.3101.

Mons. Z. T. Gramme designed his first alternating dynamo in 1878, when Mons. P. Jablochkoff was introducing his system of arc lighting (*see* Cat. Part II.), in which equal consumption of the parallel carbons of the candles was essential; this was most readily obtained by the use of an alternating current.

In this machine are combined the Gramme type of alternator with a small direct current dynamo, the current from which is used to excite its own field as well as that of the alternator. The alternating generator consists of a stationary armature, made up as an elongated Gramme ring of iron wire wound on its entire surface with right and left-handed coils; within this armature revolve six electro-magnets, arranged radially on a central shaft and excited by a separate dynamo on the same shaft. The exciter consists of an ordinary Gramme armature revolving in a two-pole field; its current is rectified by the usual commutator, then sent round its field coils and to two ring contacts, by which the circuit through the coils of the revolving magnets is completed.

The stationary armature was originally wound with six detached coils, with the core left exposed between them, but Mons. Gramme soon perceived that the output of the machine would be increased if he wound similar coils on the exposed portions of the core, and coupled them in separate circuits, giving alternating currents of different phases. This machine would now be considered a self-exciting polyphase generator.

The machine shown was made in Paris about 1880, for supplying twelve Jablochkoff candles of 4 mm. diam. (·16 in.), when running at 1,450 revs. per min.; its weight with bedplate was 605 lbs.

379. Brush's dynamo. Lent by the Brush Electrical Engineering Co., 1891. M.2401.

This type of dynamo, patented by Mr. C. Brush in 1878, has been extensively used for series arc-lighting. The armature consists of a cast-iron ring, grooved to reduce heating, provided with eight or more recesses to receive the coils which are wound in them round the remaining iron as a core. The inner ends of every two diametrically opposite coils are joined, while the outer ends are brought back into the shaft

and through an axial hole to the commutator, which is carried on an insulated sleeve. There are two sets of collecting brushes, and the commutator is double, every pair of coils having separate segments on each. When running the commutation is such that of the eight bobbins on the armature, one pair of opposite coils is in series, two pairs in parallel, and the remaining pair then passing the inactive portion of the field is cut out. The field magnets are in series, and have extended cast-iron pole pieces, there being four poles and four magnet coils.

The small example shown gives, at 1,200 revs. per min., a current of 10 ampères at 50 volts, and with 1,325 revs., 10 ampères at 90 volts. In the larger machines the cast-iron armature is now replaced by a laminated one formed of thin iron plates and ribbon—an improvement that increased the output 50 per cent.

380. Edison-Hopkinson dynamo. Lent by Messrs. Mather and Platt, 1889. M.2270.

The general arrangement of this machine follows that of the original dynamos of Wilde, Siemens and Wheatstone, and is that seen in most of the present two-pole electric generators. Edison in his early lighting installations had adopted this arrangement of magnet and pole pieces, together with the drum armature, but his magnets were usually of exceptional length and formed of several separately wound cylindrical limbs, while the armature, although built up of thin discs, had through bolts. Dr. J. Hopkinson in 1883–6, as the result of a mathematical investigation of the subject, patented improvements in this machine and showed the superiority of single magnetic limbs of moderate length wound with tape-covered wire of square section ; he also pointed out the advantage of clamping the armature core discs between flanges on the shaft, and the desirability of leaving as much of the centre of the discs as possible by avoiding the use of an unnecessarily large central shaft. In these ways, and by the provision of a sufficient section of wrought iron throughout with suitable pole and yoke pieces scraped into metallic contact, the magnetic circuit of the dynamo was completed with the least possible air gap, while the field was excited with as little loss in the field coils as was practicable. The result of these improvements was that the output of this type of machine was greatly increased and the efficiency was brought up to about 95 per cent.

The small example shown has a built-up wrought-iron magnet carried on a bed plate of zinc, so as to reduce magnetic leakage beneath the pole pieces ; the armature is of the drum type with a core built of discs of charcoal iron separated by paper, while the commutator segments are insulated with mica.

381. Ferranti's original dynamo. Presented by Messrs. Ferranti, Thompson, and Ince, 1883. Plate IX., No. 2. M.1714.

In this alternating current machine, patented by Messrs. S. Z. de Ferranti and A. Thompson in 1882–3, the field magnets are stationary and consist of two sets of electro-magnets, each with sixteen projecting pole pieces, between which the armature revolves. The pole pieces in each set are arranged alternately north and south, while poles of the two sets facing each other are of opposite polarity. The armature consists of a continuous ribbon of insulated copper running to and

fro radially in a number of layers forming eight open loops. As the space between two radial portions of the armature is equal to that between two pole pieces, the currents developed in adjacent radial portions at any instant are in opposite directions and consequently travel round the armature in one direction. There are two terminals connected with simple contact rings from which the alternating current is collected, while the magnet coils are excited by means of a separate continuous current machine.

In later forms of Ferranti alternators a different armature winding has been adopted, a number of coils being wound separately and then combined into a disc.

382. Electric motor. Lent by the Woodhouse and Rawson Electric Supply Co., 1887. M.1728.

This is a small series-wound continuous current motor, intended for driving models or similar light work; it embodies some details patented by Mr. T. Cuttriss in 1884.

The armature is of the Siemens shuttle type, and the commutator is in two sections insulated by red fibre and separated at the circumference by air gaps. When absorbing 30 watts and running at 2,500 revs. per min. it gives off about ·02 H.P.; its weight is 2·5 lbs.

383. Immisch's electric motor. Lent by Messrs. M. Immisch and Co., 1887. M.1869.

This is a series-wound motor with double field magnets and a cylindrical or elongated Gramme armature with eighteen coils. The commutator is built upon a system patented by Mr. Immisch in 1886, in which two rings of segments are employed, breaking joint, while the end of each coil is connected with a segment in each ring. The whole winding forms the usual closed circuit, but in addition the two coils directly connected with the brushes are short circuited and are so placed that the currents within them tend to reduce the distortion of the magnetic field, and the consequent sparking that results when the load is considerably varied; the brushes are, moreover, fixed in the position of no lead.

The example shown weighs 45 lbs. and when running at 1,500 revs. per min. will give off ·6 brake H.P.

384. Siemens electric motor. Lent by Messrs. Siemens Bros. and Co., 1889. M.2280.

This is a small continuous current series motor with a ring armature, and is shown driving a ventilating fan; the commutator has sixteen segments and is insulated by air gaps.

When absorbing 150 watts and running at 2,500 revs. per min. it will give off ·1 H.P.; the intended E.M.F. over the brushes is 90 volts, but these motors are also wound for other pressures.

385. Small two-pole dynamo. Received 1902. M.3215.

This is a continuous current dynamo, with its armature and field windings connected in series. The field magnet is of the enclosed or

"ironclad" type, introduced in 1886 by Messrs. E. Thomson, W. Lahmeyer, and R. Kennedy, in which the completion of the magnetic circuit is performed through uncovered iron, enclosing and protecting the windings, an arrangement that ultimately led to the completely enclosed motors now so generally employed.

The armature is of the drum type, with its fourteen coils connected with a like number of insulated segments on the commutator; a spare armature belonging to this machine is also shown, in which the original Siemens shuttle construction and a two-part commutator are employed.

386. Continuous current electric motor. Received 1903. M.3285.

This is a small two-pole series-wound motor, patented in 1891 by the Crocker-Wheeler Electric Motor Co., U.S.A.

The armature consists of a Gramme ring, wound in twelve segments and enclosed by a covering of fibre and canvas. The magnet limbs are made separately and fit into holes in the bed-plate and, in order to produce a more uniform field, the pole pieces extend further round the armature above than they do beneath it. Copper-plated carbon brushes are used on the commutator.

The starting switch, attached to the motor, has three positions:—in the first the circuit is open; in the second the circuit is closed and the two field coils are in series with each other and with the armature, so that the electrical resistance and the starting torque are at their greatest amount; while in the third the armature remains in series but the two field coils are in parallel with each other, so that the field is weakened and the speed of the motor increased.

In the larger motors of this type the armature core is built up of laminated rings, slotted to receive the windings.

The weight of this motor is 20 lbs., and with a pressure of 110 volts, and a speed of 1,800 revs. per min., its output is ·083 brake H.P.

387. Motor for alternating currents. Received 1902. M.3243.

This is a simple form of enclosed motor, patented in 1892 by Mr. A. W. Meston, in which the whole of the iron is so completely laminated as to enable the machine to be worked with alternating currents, as well as by continuous ones, without undue heating.

The field is formed by a six-armed enclosed magnetic system, built up from stamped discs with internally projecting pole pieces, held together by suitable gunmetal end flanges and through bolts, while each magnetic pole is surrounded by its own exciting coil. At one end of this casing is a stationary commutator with six sectors, one for each of the six field coils, the other ends of these coils being all connected together and with an external terminal; the other external terminal of the machine is connected with a fixed contact ring.

The armature is of the shuttle form but without winding and is built up of stampings of thin sheet iron, separated by paper but held together by through bolts and insulating end plates. Along each side of the armature's waist and secured by the end plates, are two tubes serving as carbon contact holders, being fitted with internal springs by which the contained rectangular carbons are forced outwards towards the stationary contact ring at one end of the machine and the

commutator at the other. By these arrangements the current entering through the ring terminal passes along the two carbon holders to two opposite sectors, thus exciting two of the field coils and returning through them to the other terminal. The excited magnets are so situated that they both tend to pull the armature round in the same direction, but this movement causes the commutator to switch the current into the next pair of magnets and so on, so that the armature is being continually pulled round by the pole pieces immediately in advance of it. With the object of obtaining a somewhat continuous or distributed pull when approaching the magnetic poles, the curved surfaces of the armature are not concentric with its axis.

The motor is regulated or reversed by an external arm, by which the stationary commutator can be turned through about 90 degrees.

This small example is for exerting ·125 H.P., and it weighs 23·375 lbs.

388. Single-phase induction motor. Lent by the Langdon-Davies Motor Co., Ltd., 1906. M.3430.

Polyphase motors of the induction or asynchronous class consist generally of a fixed iron ring, or stator, supplied with windings receiving two or more alternating currents, of equal frequencies but different phases, which produce alternating magnetic fields in different directions. These fields combine to form a rotating field, which causes the rotation of an internal rotor carrying conductors but not fitted with a commutator or slip rings. The driving torque is exerted owing to the reaction of the currents induced in the rotor conductors, in a similar manner to that in which a pivoted copper disc is made to rotate when placed above a powerful rotating magnet. Such motors are self-starting, but if a single-phase current be supplied to a similar stator, a simple alternating field is obtained which produces no driving torque when the rotor is at rest; when the latter is in motion, however, the currents induced in it cause the resultant field to be a rotating one and a driving torque is then obtained. A single-phase motor of this class consequently requires a starting device, and it is usual to supply the stator with an auxiliary winding which is used only when starting. By means of a "phase-splitting" arrangement, the current through this winding is made to differ in phase from that through the main winding, and a rotary field and a driving torque are thus obtained. Phase-splitting can be produced by the use of condensers, self-induction coils, and resistances. In the Langdon-Davies motor, patented in 1894, the two windings are in parallel, and a non-inductive resistance included in one of the circuits is so adjusted that the necessary difference of phase is obtained.

The experimental motor shown was made in 1891–2 by Mr. W. Langdon-Davies and was an attempt to produce with a single-phase supply a result similar to that obtained with a three-phase motor. The stator was wound with three groups of windings, each consisting of two coils in series; the groups were in parallel and the first pair had no resistance in series with them, but resistances were included in the circuits of the other pairs. A rotating field was thus produced, and the rotor consisted of a ring wound with as much copper as it would hold. The windings were arranged in six sections, each of which was short-circuited on itself and connected with the adjacent sections.

389. Continuous-current motor armature. Lent by Messrs. Crompton and Co., Ltd., 1905. M.3428.

This motor armature shows the general features of modern practice. It has a drum core built up of stamped-out discs which are provided with slots to receive the windings. These are retained in position by binding wires, and consist of a number of similar coils, wound separately on a " former." The latter is made of a set of pegs round which the wire is wound the necessary numbers of turns, and the group is then taped, insulated and opened out to fit the core. The coils are arranged two deep in the slots, and the two portions of each coil form an upper layer in one slot and a lower layer in another. The use of former-wound coils overcomes the disadvantages of the earlier hand-wound drum armature in which the wires overlapped at the ends of the core; this made a symmetrical winding impossible and might have necessitated the unwinding of the whole armature to repair one section.

In the example shown two armature sections, each of ten complete turns, are combined to form one former-wound coil, and there are consequently four groups of conductors in each slot. The armature is for a four-pole motor and its coils have the series grouping used when there are only two sets of brushes. As with this arrangement it is not possible to have a total number of conductor groups divisible by four, one of the former-wound coils is made to contain only one armature section instead of two; this device or its equivalent is frequently found convenient in small multipolar motors. The core has 28 slots receiving the same number of former-wound coils, which are made up of 55 armature sections connected with an equal number of commutator segments. The total number of conductors on the armature is 1,100 and the cross section of each is ·00152 sq. in. The motor is of 2 brake H.P. at 220 volts and 1,250 revs. per min.

Transformers.

390. Sturgeon's induction coil. Presented by D. Stone, Esq., 1861. M.586.

This consists of a single coil of wire and a mechanically-driven contact breaker; the ends of the coil are connected with the terminals of a battery, and also with two handles, while the contact breaker is included in the battery circuit. Upon the circuit being broken, a person holding the handles experiences a shock, caused by the " extra current " due to the self-induction of the coil, which can be increased by the insertion of an iron core.

The contact breaker, which was an invention of Sturgeon's, consists of a straight wire spring, with one end fixed and the other dipping into a cup of mercury. The middle portion of the spring rests upon a cam secured to a pulley, which is driven by a band from a larger pulley provided with a winch handle, so that a rapid make-and-break can be effected in the mercury cup, and high potential results obtained in the circuit.

391. Original Gaulard and Gibbs transformer. Presented by J. D. Gibbs, Esq., 1898. Plate IX., No. 3. M.3028.

All transformers resemble the well-known Ruhmkorff coil, but, as they are worked by alternating currents, they require no automatic

make-and-break arrangement. They are also usually employed to transform downward, so that the induced or derived current is at a lower pressure than the primary one. By their use electrical energy can be transmitted at high pressures to long distances, so greatly reducing the amount of copper necessary in the conductors, and can then be transformed to a lower and absolutely safe pressure at the locality where it is to be employed. Although the use of induction coils and an alternating current for the economical distribution of electricity, for lighting, and other purposes, had previously been proposed, it is to Messrs. Gaulard and Gibbs that the credit of having practically introduced this most important system is chiefly due. In 1882 they patented the use of a number of induction coils, the primaries of which were in series in a single alternating circuit, while the secondary currents were used independently for local purposes. The first public exhibition of the system was made in 1883, when an alternating current of 13 ampères was transformed down into one of 40 ampères, which was used for general lighting. Other installations soon followed upon an extensive scale, so that the efficiency and the practicability of transformer distribution were fully demonstrated.

The original experimental transformer shown consists of a core of soft iron wires, upon which is coiled a primary winding of insulated wire 3 mm. diam.; this is enclosed by six equal bobbins of insulated wire 1 mm. diam., the terminals of which are arranged along the side of the base board, so that, if desired, six induced currents can be derived from the single primary one.

392. Early transformers. Presented by F. L. Wilder, Esq., 1899. M.3049.

These two transformers formed a portion of the plant that was constructed in 1883 by Messrs. Gaulard and Gibbs when introducing their system of electrical distribution on the Metropolitan Railway. One central generating station was provided from which high-pressure alternating currents were transmitted by cables to the various stations along the line, where they were converted to serviceable lighting pressures by the arrangement shown.

In one example the transformer is cylindrical with a through core of iron, while in the other there are two coils enclosing a complete iron circuit. The windings of these coils are formed of copper washers, cut through at one place and provided with projecting tongues; the washers are insulated from each other, but are connected in series by rivets through their tongues, so as to render them equivalent to helical windings. By suitably connecting these elements primary and secondary windings were obtained which were very intimately associated, in a way that it was believed would insure increased inductive action.

393. Ferranti transformer. Lent by Messrs. S. Z. de Ferranti, Limited, 1895. M.2752.

This experimental transformer, built in 1888, in accordance with a construction patented by Mr. S. Z. de Ferranti in 1885, has a closed iron circuit, built up of thin strips filling the interior of the coil and having their ends bent over and overlapping outside; the whole are clamped together between wooden beams by two tie bolts. The windings of the

primary circuit are nearest to the centre of the coil; the secondary windings, which are outside, are made up in sections. The four terminals of the windings are brought down to the base board.

A photograph shows the transformer converting a current into one with a pressure of 10,000 volts.

394. Transformer. Lent by the Brush Electrical Engineering Co., 1891. M.2403.

This form was patented by Mr. W. M. Mordey and Major-General C. E. Webber in 1887, and has a closed magnetic circuit of simple construction.

The example shown consists of an elongated double spool of thin wood with a hollow interior. One section of the spool is wound with the insulated wire forming the primary circuit, and the other section with the wire of the secondary circuit. The iron core is in the form of a large number of thin plates of a hollow rectangular form insulated from each other by paper. These plates are slipped over the spools, and the central portion punched from each plate is slipped through the centre of the spool, so closing two magnetic circuits within which the windings are completely enveloped. The lamination of the iron, and the ventilation thus secured prevent the great loss through heating that would otherwise result. The whole appliance is clamped together by tie rods, and enclosed in a metal case for protection, and the winding wires are brought to outside terminals.

395. Transformer for continuous currents. Received 1899. M.3088.

To convert a continuous electric current at a certain pressure into one at a different pressure, it would only be necessary to cause the primary current to drive a motor connected with a dynamo suitably wound for giving a current at the desired pressure. Instead of using two separate machines, however, the same result is obtained by a single dynamo with two sets of windings in its armature and two separate commutators, so that the primary current can be sent through the armature and field magnet and the transformed current be withdrawn by the second commutator; this is the arrangement followed in the small example shown.

The armature, which is of the elongated Gramme type, is arranged vertically with its spindle extending down to a pivot-bearing at the bottom of a long sheave arranged between the magnets. There is no external top bearing, but the two commutators, which are in the form of annular discs, are arranged on the upper face of the armature.

This transformer is intended for converting a current of 20 ampères at 12 volts into one of 4 ampères at 45 or 50 volts for lighting a single arc lamp.

396. Continuous-current transformer. Received 1904. M.3379.

This motor-generator is of the circular enclosed type, and has the arrangement of armature and field magnet patented by Messrs. R. Lundell and E. H. Johnson in 1892–7.

The field magnet consists of two hemispherical portions, bolted together, each having one of the poles cast with it. A single exciting coil fits obliquely round the poles and embraces the armature, which is slotted and has two windings connected with separate commutators. To one of these the current to be transformed is led and drives the armature as a motor, while the other winding acts as a dynamo and is so designed as to generate a current at the required pressure. As the reactions due to the motor and generator parts of the armature practically neutralise each other, the commutator brushes occupy fixed positions and there is very little sparking.

This machine makes 1,180 revs. per min. and transmits about 1 H.P., transforming a current of 4·5 ampères at 200 volts to one at 100 volts pressure. The field exciting coil consists of 9,000 turns of wire, ·018 in. diam., and is connected as a shunt across the 200 volt leads. One portion of the field magnet is shown detached.

397. Safety device for transformers. Lent by Killingworth W. Hedges, Esq., 1898. M.3030.

When transformers are used for the distribution of electric energy for lighting, the potential in the primary circuit is invariably much higher than that on the lighting system, and as a leakage in the transformer might place the lighting circuit in contact with the primary, some form of apparatus is necessary to limit the potential of the secondary circuit. The device shown, which was patented by Mr. Hedges in 1888, bears some resemblance to the lightning arresters used on telegraph lines.

The apparatus consists of an exhausted glass globe containing two platinum terminals nearly in contact; one of these wires may be placed to earth while the other is connected with the secondary system, so that if the tension in that system becomes dangerously high, the electricity can strike across the gap in the low resisting atmosphere within the globe, and so be taken to earth. This escape current may be used to move a switch that breaks the primary circuit. The whole apparatus is insulated, and enclosed by a protecting cover.

Secondary Batteries.

398. Secondary batteries and plates. Lent by Messrs. Elwell Parker and Co., 1888, and presented by the Electrical Power Storage Co., 1892. M.1897 and 2480.

The earliest form of secondary battery was invented by Planté in 1859, and consisted of a number of lead plates coupled up in series and converted into a battery by sending through them a current at a sufficient pressure to decompose the acid solution in which they were placed. The electrolytic action covered the alternate plates with lead peroxide, and when the charge was stopped this secondary battery would act as a primary one by sending a powerful current, which, however, could only be kept up for a very limited time owing to the small amount of lead peroxide that could be retained on the plates.

Faure, in 1880, rendered this battery of great practical importance by increasing its storage capacity. This he accomplished by first covering

the plates with oxides of lead, and then "forming" them by passing through the battery a charging current, which raised one of the oxides and lowered the other. The greater mass of oxide so rendered available increased the storage capacity to a thoroughly serviceable amount.

As now constructed, these accumulator cells consist of lead plates fashioned so as to retain the oxides employed. The negative plates are cast with a grooved surface, but the positive are cast in the form of a grid to retain more securely the oxide, which on these plates has a great tendency to separate. The series of plates is soldered up in parallel and placed in a rectangular vessel of glass, but for some purposes lead or vulcanite is preferred. The containing vessel is filled with dilute sulphuric acid, and during discharge the density of this solution is lessened by the combination of some of the acid with the oxides in the plates, while during charging this acid is returned to the solution, whose density is thereby increased. Hence an ordinary hydrometer placed in the solution will enable the stored energy of the cell to be ascertained with a fair amount of accuracy by simple inspection. The time required for charging a battery is about equal to that occupied in its continuous discharge, but the safe rate of discharge is limited. The energy returned by the cell is about 80 per cent. of that put into it, and the discharging E.M.F. is 2 volts.

399. Secondary batteries. Lent by the Epstein Electric Accumulator Co., 1894. M.2571.

The Epstein construction of accumulator is shown by cells in glass and vulcanite, together with plates in the various stages of formation. The ribbed leaden plates are first boiled in dilute nitric acid and dried in the air; these raw electrodes are then converted into positive plates by electrolysis in a sulphuric acid solution, and those that are required as negatives are reconverted by a reversed electrolysis. This method of formation, which dispenses with the use of paste, resembles the original system followed by Planté.

400. Thermo-electric generator. Received 1900. M.3100.

Since Seebeck's discovery, in 1821, of the electric current obtainable by maintaining the junction of certain dissimilar metals at different temperatures, many attempts have been made to provide a practical generator of electricity by the direct conversion of heat in this convenient manner. Marcus, in 1865, constructed a thermo-couple with elements of nickel-brass and antimony-zinc, which, having a minimum melting point of 600 deg. C., gave ·055 volt per couple. Clamond constructed a pile of 6,000 couples, from which he obtained ·036 volt per couple, and found that 5 per cent. of the heat supplied was converted into electrical energy. The usual antimony and bismuth couple gives ·0012 volt for a difference of 10 deg. C., but the melting point very much restricts the superior temperature permissible.

The pile shown was patented and commercially introduced in 1894–6 by Mr. J. B. Cox. One element is an alloy of antimony and zinc, and the other of copper and nickel, the difficulty of the junction being overcome by fusing the couples together, so that the junction is shaded off and the sudden change in material avoided. The pile or battery is built in rings, prepared by arranging a sufficient number of strips of the copper alloy in a heated steel mould into which the antimony alloy is

then cast; the mould is also heated for a considerable time after casting to facilitate the union of the elements. Several of these rings of elements are superposed and connected in series, and then protected by embedding in vitrified cement to prevent their oxidation. A metal jacket encloses the whole cylinder thus formed, and is kept cool by water circulating through it, while the inner portion of the pile is heated by a central gas burner provided with deflectors to retard the escape of heat. The external diameter of the apparatus shown is 7 in. and the height of the pile 5 in.; each ring contains 15 couples, and there are 7 rings. When the burner was consuming 2·5 cub. ft. of gas per hour, a pressure of 5 volts on open circuit was obtained, and it is stated that from a large coal-burning generator of this type the current was 5 ampères at 55 volts.

APPLIANCES FOR DISTRIBUTING ELECTRICAL ENERGY.

The employment of electricity as an illuminating agent, and as a means of driving motors, has led to the development of numerous systems for distributing the current from central generating stations. Nearly pure copper is the conducting medium almost universally employed, but in its application and in the methods of insulation and protection resorted to, when overhead conductors are inadmissible, remarkable divergencies are to be found. The commercial employment of electricity has, moreover, led to the introduction of a great number of special fittings and accessories, corresponding with the valves and other details, which followed the development of the steam engine and of lighting by gas, but only a few of these are at present shown.

The amount of electricity involved in telegraphic signals is so small that the conductors employed bear but little resemblance to those necessary when transmitting in quantity, and are therefore placed in the section devoted to telegraphy.

401. Casing for electric leads. Presented by J. S. Beeman, Esq., 1897. **M.2999.**

These are three samples of casing made from asbestos paper, and introduced about 1882 for building into walls. In one example the tube is divided by a central diaphragm.

402. Specimens of insulated conductors. Lent by the India-rubber, Gutta Percha, and Telegraph Works Co., 1890. **M.2356.**

This is a series of specimens of conductors used for conveying electricity for electric lighting and similar purposes where quantity is required. A table attached gives particulars of the weight, resistance, and general construction of the specimens. The conducting copper is usually tinned on the outside, and where considerable sectional area is required it is obtained by increasing the number of wires, rather than

by using wires of larger diameter, the built-up wire being vastly more flexible than the solid rod and possessing other important practical advantages. The insulating material is of several kinds, and the outer covering usually acts chiefly as a mechanical protection to the insulating layers. Lead casing is now frequently employed, as it affords considerable protection and is at the same time fairly flexible. The lead tube is made in the usual way by squirting, but the prepared cable passes through the die at the same time, so that the tube is formed upon the cable and in perfect contact with it.

403. Electric cables with paper insulation. Presented by the British Insulated Wire Co., 1900. M.3112.

Although gutta percha and india-rubber have long proved themselves to be excellent insulators, they are expensive materials, and have high inductive capacities which interfere with their employment for alternating currents or on telephonic mains. The use of paper as an insulator was first tried on a large scale by Mr. S. Z. de Ferranti in 1889, when he insulated the concentric cable conveying the energy from the Deptford generating station to London, at a pressure of 10,000 volts, by means of paper saturated with paraffin wax. When dry paper is employed, it is wrapped loosely round the conductors and enclosed in a lead tube for protection, the dielectric being chiefly air; owing to the difficulty of excluding moisture, the paper is now usually saturated with an insulating material of the nature of paraffin wax.

In the cables shown, the prepared paper tape is wrapped round the core in overlapping strands and then passed through dies which consolidate the surface; the cable is subsequently heated, to expel any moisture, and immediately submerged in an insulating compound, after which it is passed through an annular die in the base of a cylinder containing lead so arranged that a lead tube is squirted round the cable as it passes through the fixed die.

404. Electric switches. Lent by Killingworth Hedges, Esq., 1902. M.3236.

These two examples, which were made by Mr. Hedges in 1880, are arranged to reduce the evil resulting from the "sparking" which takes place when a circuit is broken. In one case there are trailing pieces which remain in contact after the main contact is broken, so that the final break takes place where the sparking will be harmless; in the other switch the contact pieces are readily renewable sparking plates.

405. Main switches. Lent by Killingworth Hedges, Esq., 1902. M.3235.

In these switches, patented by Mr. Hedges in 1881, the terminal plates are arranged as sectors of a circle, with similar sectors of insulating material between them, while the contacts are made by bars turned by a central handle. The contact pieces are pressed home by helical springs, but are free to rotate, so that a polishing contact is obtained. These contact pieces may be the terminals, and the circuit be completed by a copper bar, as in the four-way switch shown; or the central pivot may be one of the terminals as in the two-way switch.

406. Early switches. Lent by Killingworth Hedges, Esq., 1902. M.3237.

These two examples show the construction of switch introduced in 1881 by Lord Kelvin for domestic lighting. The contact is made by a sliding bolt, which presses on a leaf spring, so arranged as to give rubbing contacts on both terminals. One of the switches is shown combined with a bracket lamp holder.

407. Electric switches. Lent by the Electrical Power Storage Co., 1885. M.2215–6.

These are for making or breaking an electric circuit through which a strong current may be passing, provided the voltage is not excessive; where high pressures have to be dealt with, a longer and more rapid break is generally employed so as to diminish the chance of arcing.

In one switch a swivelling bar, with the ends turned down, is provided with handles at each extremity, and carried on the central point which is secured to the centre of the base. To this base also are attached the two terminals of the circuit. To secure good contacts the terminals are provided at their ends with C-springs, between the jaws of which the rotating contact pieces can be forced. The springs are built up in three thicknesses so as to retain sufficient elasticity while giving the requisite amount of contact surface. These springs can also be tightened down to neutralise any wear.

The other switch is the same in principle, but has eight contact pieces instead of two; these are arranged in a circle and the four adjacent ones on one side are coupled to a common terminal, while on the other side four separate terminals are provided. In this way the electric current can be directed into four separate circuits as desired. By the employment of the double handles considerable force can be exerted on the switch without straining the pivot.

408. Electric switch. Lent by the Edison and Swan United Electric Light Co., 1890. M.2358.

This is a quick-break switch for a current of 5 ampères. In it two connected brass tongues are arranged to be brought down to the terminals of the circuit by an external knob; they are retained by a knuckle lever action, but in being forced down a spiral spring is compressed. When the knob is pushed over to break the circuit considerable movement takes place before there is any tendency to withdraw the contact piece, but when once this is started the spring rapidly completes the movement, thus preventing the arcing that might follow if the contact were slowly broken. The switch is carried on an insulating base and protected by a metal cover.

409. Automatic electric switches. Lent by the Electrical Power Storage Co., 1885. M.2217–8.

These switches are arranged to break the electric circuit automatically as soon as the current falls below a certain amount, or they can be arranged to break the circuit when the voltage is below a settled limit; they were specially prepared for use in connection with the charging of secondary batteries.

In one example the switch consists of an electro-magnet of horse-shoe form, provided with pole pieces between which swings an iron tongue, also fitted with a coil and being also an electro-magnet. The current is conveyed to this tongue by two flexible copper straps. A stout contact piece secured to the insulated base makes contact with the tongue when the latter is pulled over, and the current traversing the electro-magnets retains the tongue in this position against the pull of a spring as long as the intensity of current is sufficient. The coils of the magnet have also a winding of fine wire which can be used for modifying the action of the switch, and two separate tongues which are placed in contact when the switch is released may be used to direct attention to the fact of the switch having acted.

In the other example, which is simpler, the switch arm is, by a spring, pulled in one direction, and by the insulated handle can be pulled into the closed position, where it is retained by a catch that is held down by a straight electro-magnet. When the attraction of the magnet diminishes, the catch is released and the circuit is broken. To diminish the friction of the catch it is provided with a small roller.

410. Starting-switches for shunt motors. Made by the Ward Leonard Electric Co. Received 1904–5. M.3380 and 3418.

When starting a continuous current motor, it is usual to place a graduated resistance in series with the armature and thus prevent the abnormal rush of current which would otherwise occur before a protecting back E.M.F. had been developed; as the speed of the armature and the back E.M.F. increase this resistance is gradually cut out.

The resistance portion of the switch shown consists of a series of coils arranged between contact studs over which the switch arm is moved. The arm is connected with the mains, and as it is moved from stud to stud towards the right, the resistance in the armature circuit is gradually reduced, being altogether cut out in the extreme right-hand position. The arm is retained in that position owing to a soft iron armature mounted on it being attracted to the poles of an electro-magnet, the coil of which is included in the motor field circuit. If the electro-magnet ceases to be excited, owing to a failure of supply or to a break in the field circuit, the attraction ceases, and the switch arm is pulled back to its initial position by a spring. This arrangement, known as "no-volt release," ensures that the whole of the starting resistance is in series with the armature when the supply is renewed, and also protects the armature from receiving a destructive current when there is no field.

A metal blade is mounted on the same axis as the switch arm and the two are urged together by a spiral spring. The blade makes contact with a stud connected with the line, and is retained in position by a catch. Included in the motor circuit is a solenoid, which is surrounded by an iron casing, and is fitted with an iron core resting on an adjustable stop. When the current exceeds a certain amount, the core is sucked into the solenoid and strikes against a piece connected with the catch, thereby releasing the blade and breaking the circuit. This device constitutes an "overload release" and protects the armature from receiving too great a current owing to an excessive overload, or to cutting out the resistances too quickly when starting.

The electrical connections are such that the motor armature and

field are joined in a closed circuit which is never opened, thus providing a path for the discharge produced, when the main circuit is broken, owing to the self-induction of the shunt windings.

The example shown is for use with a shunt wound motor of ·5 brake H.P. on a 220-volt circuit. Its resistance coils are placed in a cast iron box containing sand, and are insulated by asbestos and mica, the contact studs being mounted on the slate slab which is protected from overheating by a sheet of asbestos. A partly sectioned example of a similar rheostat is shown.

411. Enclosed liquid reversing switch. Lent by the Sandycroft Foundry Co., Ltd., 1905. M.3397.

This switch for starting and reversing a continuous current motor was patented by Mr. J. H. Woolliscroft. in 1902. In place of the metallic rheostat usually employed in motor starters it has a liquid resistance consisting of iron plates dipping into a solution of either caustic or common washing soda, the resistance being regulated by varying the area of the immersed portions of the plates.

An enclosed iron drum, mounted on insulated bearings, is nearly half filled with the solution and carries two internal iron plates, nearly semicircular in shape, which are insulated from the drum but electrically connected with the upper half of an insulated split contact ring. Three foliated copper brushes connected with terminals engage with the ring and a central foliated brush connects the drum with a fourth terminal.

When the operating handle attached to the drum is vertical, the internal plates do not touch the liquid and the armature circuit in which the liquid resistance is included, is broken. When the handle is moved in either direction the plates enter the liquid and close the circuit, while further motion of the handle, by increasing the area of the plates immersed, gradually reduces the resistance until when the handle is horizontal, a small plate connected with the drum comes into contact with the outer edge of one of the contact brushes and short-circuits the resistance. The direction of the current through the armature depends on the direction in which the handle is moved, so that reversal can be effected. A diagram of wiring connections is shown. Water can be added through a plugged hole to make up for evaporation losses.

This example is suitable for use with a continuous current motor up to 6 brake H.P. and a voltage up to 500. It is connected with the mains by a double pole switch and, if required, can be fitted with no-voltage and overload releases.

Owing to the high specific heat of water, liquid resistances do not become heated so quickly as metallic ones, and can be adjusted gradually without any intermittent contacts to produce sparking. They form convenient non-inductive loads for testing purposes.

412. Starting switch for shunt motor. Lent by the Brush Electrical Engineering Co., Ltd., 1905. M.3421.

The resistance portion of this continuous-current motor-starter consists of a number of grids made of a special alloy which are mounted on a frame inside a cast-iron box provided with ventilating holes. The

grids are connected at intervals with contact pieces on a slate slab which is fixed to the front of the box and carries the switch together with "no-volt" and "overload" releases.

There are two switch arms, both of which are urged by springs towards the left; one constitutes the main switch and is controlled by the automatic gear, while the other, to which the operating handle is attached, regulates the starting resistance. To start the motor, the handle is moved to the extreme right and carries both arms with it. The main switch arm then closes the motor circuit, and the whole of the starting resistance is in series with the armature. As the speed of the armature increases, the handle is moved slowly back over the contacts, causing the resistance to be gradually cut out.

A "no-volt" release coil is included in the motor field circuit and excites an electro-magnet attracting an iron armature attached to the main switch arm, which is thus retained in the extreme right position. In the event of a failure of supply or a break in the field circuit this attraction ceases, and the main switch arm is pulled back by its spring to the left position and breaks the circuit; excessive sparking is prevented by a magnetic blow-out. The latter consists of an auxiliary contact piece, which is mounted on the main switch arm, and makes the final break between the poles of an electro-magnet excited by the overload-release coil. This coil also excites another electro-magnet, which is fitted with a hinged iron armature resting upon an adjustable stop. When the current exceeds a certain amount, this armature is raised and a bridge piece, mounted upon it, then touches two fixed contacts connected with the terminals of the no-volt release coil which is thus short circuited. The main switch arm is consequently released, and breaks the circuit. This overload release is operative during the starting process as well as in the running position and prevents any injury due to cutting out the starting resistance too quickly. As the main switch arm does not touch the resistance contacts, the latter are relieved of all destructive sparking.

The example shown is for use with a motor of 15 brake H.P. on a 220-volt circuit.

413. Magnetic cut-out. Lent by Messrs. Woodhouse and Rawson, 1887. M.1724.

This magnetic cut-out, patented by Messrs. Cunynghame, Woodhouse, and Rawson in 1883, is an arrangement by which an electric circuit is automatically broken when the strength of the current exceeds a certain limit. It consists of an inclined electro-magnet fitted with a horse-shoe keeper which is capable of swinging on a horizontal axis. The keeper is provided with two curved arms of copper which dip into two mercury cups formed in a wooden block. The current entering the apparatus passes round the electro-magnet and down into one of the mercury cups, then across the cup to the contact piece connected with the keeper, along the keeper and down the other contact piece, which completes the circuit by dipping into the mercury cup containing the other terminal. When the current exceeds the prescribed limit, the magnetic attraction becomes sufficient to pull the keeper and its attachments over, so instantly lifting the two contact pieces from the mercury cups. A set screw permits the position of the keeper being adjusted to the desired intensity of breaking current.

414. Large fusible cut-outs. Lent by Killingworth Hedges, Esq., 1902. M.3238.

In these fuses, by Mr. T. A. Edison, the smaller example, which is for a current of 500 ampères, is a stamping from a sheet of alloy, and has the holes for the terminal screws at right angles, to facilitate its insertion under the clamping washers. The larger fuse is for 2,000 ampères and is similarly arranged; its terminals are, however, of copper, the fusible metal being confined to a central bridge.

415. Fusible cut-outs. Lent by Killingworth Hedges, Esq., 1902. M.3239.

Three modifications are shown of a type of fuse introduced by Lord Kelvin with the object of minimising the wasteful resistance occasioned by such appliances. The fuse consists of two copper wires soldered together at the middle and held between terminals in such a state of stress that, when the solder softens through the heating of the joint, the wires spring apart, thus breaking the circuit; or else a very short length of fuse wire is employed and kept under tension, by a helical spring formed in the conducting wire. The smallest example shows a single light fuse and spring, and is contained in a glass tube fitted with end terminals so that it can be readily replaced under the spring clips which form the attachment.

416. Fusible cut-outs. Lent by Killingworth Hedges, Esq., 1902. M.3240.

"Cut-outs," or short pieces of fusible wire, were early found to be necessary safety appliances in the practical application of electricity, but these examples show a modification patented in 1882 by Mr. Hedges, by which the replacement of a fuse that has blown is facilitated owing to the fusible foil employed being attached to plates of mica or other insulating material which render it more rigid.

In two of the specimens, a spring clip from one terminal holds a loop of foil and an enclosed mica plate against the other terminal; in another example two paths are offered to the current, but one of them is kept in reserve by the insertion of a piece of paper which can be quickly removed, thereby throwing in the reserve fuse should the working one fail. In a larger example the same result is obtained by the use of two fuses, fixed in position on a contact plate having two holes and a single plug, so arranged that should the working fuse fail, the second one can be immediately put into the circuit by removing the plug to the other hole; the original gap is at the same time thrown out ready for the replacement of its fuse.

417. Fusible cut-outs for high tensions. Lent by Killingworth Hedges, Esq., 1902. M.3241.

These show two arrangements, introduced by Mr. Hedges in 1883, for destroying the arc which results when a fuse wire is volatilised in a high tension circuit. In both examples the fuse wire, or foil, is carried round a block of slate, directed in vertical guides but free to drop when the fuse melts, so that it shall rapidly break the circuit and cut through any arc that may be formed.

418. Fusible cut-outs. Lent by the Edison and Swan United Electric Light Co., 1890. M.2358.

These cut-outs are intended to fuse and so break the circuit when through some accident an excess of current passes; the limit, which in these examples is from 5 to 20 ampères, depends on the sectional area of the fusible wire by which the terminals are connected. The apparatus is mounted on a porcelain base and protected by a metal cover, which can be readily removed when it is necessary to insert a fresh fuse.

419. Fusible cut-outs. Lent by Messrs. Woodhouse and Rawson, 1887. M.1730.

In these cut-outs the fusible metal is in the form of foil, and to give it the necessary strength, to withstand the handling and fixing in position, the foil is folded on to a strip of insulating fibre. The ends are notched out so that the fuse can be replaced without removing the binding screws.

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420. Choking coil. Received 1904. M.3329.

When it is necessary to reduce the pressure in an alternating current circuit, a coil, having a small resistance but considerable self-induction and known as a choking or impedance coil, is inserted. The current in such a coil lags nearly 90 deg. behind the volts, and consequently the energy lost is less than it would be if simple resistances were used, as in continuous current circuits.

The example shown consists of a single winding round a laminated core built up of sheet iron stampings, and its choking effect can be reduced by sliding the core out of the coïl. It is designed for use with arc lamps worked in parallel from alternating current mains, one coil being inserted with each lamp so as to perform the double office of steadying the current and absorbing the superfluous pressure.

Choking coils are also used in continuous current circuits to reduce by their self-induction the rush of a current when the circuit is closed.

421. Economy coil. Received 1904. M.3328.

Although choking coils waste less energy than resistances, when employed to lower the pressure for alternate current arc lamps, the consumer does not get the full benefit of their action if the meter employed records in ampère-hours. By the use, however, of a combined form of transformer and choking coil known as an economy coil this defect is removed.

The example shown consists of a continuous laminated iron core mounted on a porcelain stand. It has two coils wound in series, with terminals such that one coil is in series with the lamp and the other in parallel with it. The series portion acts as a choking coil in lowering the pressure, and also as the primary of a transformer of which the second coil forms the secondary. This secondary supplies part of the current to the lamp which consequently receives more current than passes between the mains. The total result is practically the same as if a step-down transformer were used, the lamp receiving almost the same number of watts as are taken from the mains.

The coil shown is for use with a 100-volt circuit, and produces a drop of pressure to 33 volts at the lamp terminals. The portion of the coil constituting the primary can be lessened and the pressure at the lamp terminals increased by altering the position of a screw-contact piece.

MECHANICAL MEASURING INSTRUMENTS.

Under this heading are included the various appliances used in measuring the different quantities entering into the execution of industrial work; the more delicate instruments employed in scientific investigations are not represented, as they form an independent collection which is arranged in the Western Galleries of this Museum. As the application of the results of scientific investigation extends, the number of measuring instruments used in the arts continually increases, a change that is particularly noticeable in connection with the rapid adaptation of electricity to industrial work, whereby many instruments have been introduced into mechanical workshops which, but a few years ago, were never seen outside a scientific laboratory.

Number.—The measurement of number is the simple duty performed by the counter found in nearly all registering instruments; but by this mechanical counting an enormous amount of monotonous mental labour is avoided and the possibility of error greatly reduced, while the labour of attendants is almost entirely dispensed with. The modern calculating machines, by which much of the drudgery of arithmetical work is avoided, are elaborate developments of the same simple mechanism, in which the chief element is some form of revolution counter, consisting usually of a series of trains of wheels with a step ratio of ten to one, or an equivalent; this is now generally so arranged that the advance is intermittent instead of continuous, so that the reading is not complicated by figures in intermediate positions.

Length.—In the measurement of length, from the time when three good barleycorns formed the standard inch, the necessity for some more accurate unit of measurement has been continually experienced; such progress has, however, now been made that, for all practical purposes, standards of length of sufficient accuracy are generally available for reference. In London there is a series of English units, arranged for public use on the north wall of Trafalgar Square, while at the entrance of the Western Galleries of this Museum is exposed a shorter series of both English and metrical units.

The relative merits of comparison by sight and by end measurement have been frequently discussed, as both systems have advantages, but the higher results as regards accuracy have been secured by the end measurement system. For rough measurements we all use sight methods, and by magnifying the readings the accuracy of this very convenient system can be enormously

increased ; but, for general mechanical work of high accuracy, end measurement is chiefly relied on, although in many instances the two systems are combined. Sir Joseph Whitworth developed the present system of end measurement, and generally introduced it into workshop practice, at the same time applying it to the construction of machine tools and gauges, which he thus brought to a degree of accuracy that has not since been materially improved.

Volume.—For measuring volume we usually determine the dimensions of the containing reservoir or receptacle ; but, where fluids are supplied by measurement, or where the quantity discharged has to be recorded, meters of some form are usually employed. Gas meters, whether wet or dry, really record the number of times that a certain vessel, in the form of a cup or bellows, is filled by the gas passed, a method equivalent to measuring the contents of a tub by bailing it out by a vessel of known capacity. Positive water meters work on the same principle ; but a very large class of water meters register from the velocity with which the water issues from a constant orifice, this velocity being usually determined by the rotation of a fan ; small rotating fans are also generally used for measuring the quantity of air passed for ventilating and similar purposes. In the measurement of large quantities of water, as in the case of rivers and streams, the velocity may be determined approximately by floats or fans, but where the water flows over a weir or through a notch, the volocity is more readily determined by accurately measuring the head of water over the sill.

Mass.—The mass of a body is the property upon which its weight depends, and in all industrial work the weight is the quantity determined. There are three types of apparatus in use for weighing, of which the oldest is the scale with equal armed beams and standard weights ; this is still the most accurate method, but for heavy weights becomes so inconvenient as to be practically impossible. The second plan is by varying the leverage, as with the old steel-yard ; the third and most generally employed system is a combination of the two preceding ones, and is seen in the various forms of modern platform weighing machines. The estimation of weight by the compression produced on a calibrated spring is a convenient method of determining mass, but does not admit of the same accuracy as the lever machines. Duckham's machine is a very compact form of spring balance, and is capable of dealing with the heaviest loads while they are being lifted ; in it the spring is that within the pressure gauge upon which the reading is taken.

Velocity.—Speed indicators, for the determination of velocity, form a very large class of instruments, but in the majority of cases in the arts the rate of revolution of some shaft is the quantity that has to be determined, and for this purpose the centrifugal force arising from the speed is generally the quantity most easily measured. Watt's pendulum governor, in a much modified form, and generally spring loaded, is the acting mechanism in most tachometers, although a revolving mass of fluid is sometimes preferred. For temporary purposes speeds are generally determined

by the aid of a watch and some counting device, while in a few forms of speed indicator these two instruments have been combined in one apparatus.

Pressure.—The ordinary steam gauge, in which the pressure is indicated by the movement of an index over a graduated dial, remains the most popular appliance for measuring fluid pressure. In the earliest form of this class of gauge, movement of the finger was derived from that of a piston loaded with a spring, but very soon the piston was replaced by a diaphragm. In 1849, however, Mons. Bourdon replaced the diaphragm by the now generally used elliptical tube, his valuable invention being the result of noticing while he was attempting to remove some indentations from a coiled copper pipe by pumping water into it under considerable pressure, that the coil showed a slight tendency to unwind as the pressure was increased. He afterwards made a coil of pipe to which he fixed a finger, and then secured it to a board, and this simple arrangement he found gave a reliable indication of the pressure within the coil; it was afterwards simplified by using only a short portion of the coil and magnifying the movement by toothed gearing.

The earliest steam gauges in use were columns of water or mercury, usually contained in a U-tube, and such arrangements, being exceedingly accurate, are still generally employed for testing the more usual gauges, in which the measurement relies on the elasticity of the material in some form of spring. Gauges have also been used in which the pressure is indicated by the compression of a volume of air contained in a closed glass tube, mercury acting the part of a piston, but the correction for temperature is so large that this arrangement is but seldom resorted to, except for very high pressures or in experimental work.

Tenacity and Similar Properties of Materials.—Testing machines, for determining the elasticity and ultimate strength of materials used in construction, are now of the greatest importance, since economical design can only be carried out when the properties of the materials employed are known with sufficient accuracy; moreover, frequent testing is the only certain way of securing that the materials approximate sufficiently to the intended standards. During recent years a great improvement has been made in testing machines, in addition to their increase in size and accuracy, by the employment of an automatic recording apparatus by which a diagram is drawn showing the rate of extension as the load increases.

Temperature.—For the measurement of temperature, mercury-in-glass thermometers remain the most convenient and accurate instruments for practical use, where the temperatures are not too high. Owing to the certainty of its graduations the gas thermometer is generally used as a standard of reference. During recent years a great advance in the measurement of high temperatures for industrial purposes has been made by the introduction of electrical arrangements, some of which depend upon the variations of the electrical resistance of platinum with temperature, while in others

thermo-electric couples are employed which, combined with delicate galvanometers, give readings capable of being registered by self-recording attachments at any distance from the furnace.

Work.—The measurement of work done or energy expended, has always been of importance, but came more particularly into prominence after the invention of the steam engine. Watt found that his engines were frequently required to do work that had long been performed by animal power, so to determine the work that a horse could do, he made the animal pull a weight of 150 lbs. upward from a coal pit, by means of a rope passing over a pulley; this weight the horse lifted at the rate of 220 ft. per min., thus doing work equal to 33,000 ft. pounds per min., which result was the final estimate that Watt adopted as his "horse-power," although he knew that a horse could not regularly give out so much energy. When, however, Watt's engines were paid for by their horse power, he complained that "the power of a horse is growing to that of an elephant," so that even his ample allowance did not satisfy all parties. Recent experiments in traction have shown, however, that although Watt's estimate of the average power of a horse was exceedingly liberal, yet in emergencies and on hills the average horse exerts for considerable periods a very much greater effort than Watt estimated, a deduction that is confirmed by the large reserve of power with which motor cars have to be provided.

To measure the power of the work done by his engines Watt invented the steam engine indicator, and this intrument, greatly improved and modified to meet the requirements of present steam engine practice, remains by far the most important appliance for the measurement of work. Watt's indicator is, however, only applicable to power generated or transmitted by fluid pressure; for other purposes some form of dynamometer is generally used in which the work given out by the motor is measured while it is being absorbed, or else while it is being transmitted through the apparatus. Absorption dynamometers are of very simple construction, and can be made to give most accurate readings; up to the present the construction of a reliable and convenient transmission dynamometer remains to be completed, as those in general use interpose considerable frictional resistance, which, unfortunately, does not remain constant. Electrical transmission of power is becoming so general, that it can now be considered a simple and convenient method of measuring the quantities formerly generally determined by a transmission dynamometer; the chief objection to this method is that it relies upon the readings of electrical instruments, the accuracy of which cannot easily be checked in an engineering works.

Electricity.—The remarkable strides that have been made in the practical introduction of electricity, and its general use in industrial work, have caused the invention of a large number of electrical measuring instruments which, while sufficiently accurate, will give a simple reading that can be understood by any attendant

as easily as the reading of a pressure gauge or a gas meter, and so be suitable for workshop use. The principle of the laboratory galvanometer is found in a large number of the ammeters and voltmeters in general use ; permanent magnets, however, are generally discarded and, owing to the larger currents employed, the needle is carried in bearings rather than by a silk fibre, so sacrificing sensitiveness to greater durability and strength. When high potentials are employed, the direct attraction of oppositely electrified surfaces is the principle upon which many of the latest voltmeters work; the great simplicity of the relationship of the three leading quantities in electrical measurement gives, however, considerable choice in the way in which any one of them is determined.

The public supply of electricity has created an immense demand for meters, by which the electrical energy consumed by householders can be registered, in a similar way to the gas consumption. Some of these instruments have their readings controlled by the pressure, as well as by the quantity of electricity passing, but in several types the quantity is alone recorded, so that the accuracy of the result, in energy consumed, depends upon the steadiness with which the normal pressure in the mains is maintained.

Measurement of Number.

422. Watt's engine counter. Contributed by James Brown, Esq., 1861. M.526.

When Messrs. Boulton and Watt were introducing their improved steam-engine for pumping in the Cornish mines, payment in many cases was made by the pumping work performed. This work was recorded by a counter, fixed on the engine beam, and constructed to register the number of strokes performed. It is stated that the mine owners objected to the readings of these instruments, on the ground that they counted the short strokes of the engine equally with the complete ones.

The apparatus consists of a locked box containing a pendulum which, by a reversed escapement, drives a series of counting wheels; indexes on the spindles of these wheels register the number of oscillations on a series of dials advancing in powers of ten.

423. Revolution counter. Presented by the Institution of Civil Engineers, 1868. M.1082.

This is an old form of revolution counter. The gearing consists of a worm and worm-wheel, together with a train of spur-wheels for reducing the speed, and three dials over which four indexes move continuously but not all in the same direction, so that the reading is difficult, particularly at high speeds.

424. Revolution counter. Presented by the Institution of Civil Engineers, 1868. M.1083.

This is an old counter similar to No. 423, but one of the spindles is made considerably longer and enclosed within a wooden arm, in the

extremity of which the worm and worm-wheel are arranged. The worm spindle terminates in a small coupling that has been driven by a rotating wire.

425. Five figure revolution counter. Contributed by R. Roberts, Esq., 1858. M.183.

This instrument, invented by Mr. Roberts, consists of five wheels, each marked with the ten numerals on the edge; all but the first wheel run loose on the horizontal shaft of the counter. On one side of each wheel is a ten-pointed recess, and on the opposite side of the wheel is an eccentric boss; on each boss is a loose ring from which projects downward a tail that prevents its rotation, while from the face of the ring three teeth, which engage in the recesses in the adjacent wheel, project. The result of this connection is that each wheel is driven at one-tenth of the speed of the wheel driving it, so that read along a horizontal line the revolutions are indicated in a very convenient form for reading; the advance of each wheel is, however, continuous, so that the trouble of half figures is not avoided.

426. Revolution counter. Contributed by R. Roberts, Esq., 1862. M.726.

This counter indicates by the use of two concentric revolving dials geared together by an epicyclic train. The dials are on a central fixed stud, which also carries a double-ended pointer. The larger dial has a toothed edge and is driven by a worm from the shaft whose revolutions are to be counted; the ratio of the gearing is 1 : 100, so the dial counts up to 100 revs. The dial carries at the back a pin, upon which runs a long pinion gearing into a spur wheel of thirty-nine teeth fixed to the stud, and also into a wheel of forty teeth secured to the back of the inner dial. By this means the inner dial, which reads up to 4,000, is rotated at 1-40th of the speed of the outer one.

427. Electrical counter. Wheatstone Collection, 1884. M.2170.

This instrument, patented by Sir C. Wheatstone in 1858, consists of two dials over which pointers are moved by gearing from a step-by-step propulsion actuated by an electro-magnet. The poles of the latter are adjacent, and between them oscillates a magnetised needle carrying the arbor of a ratchet wheel of fifteen teeth, which engages with a fixed pawl and is thus slowly turned by the currents received; this motion is recorded by a counter.

428. Revolution counter. Lent by R. Applegarth, Esq., 1879. M.2514.

This is a pocket counter, patented by Mr. A. Sainte in 1877, provided with fittings by which it will readily connect with any revolving shaft, if the end be accessible. When this is not the case a small wooden roller, the circumference of which is one-tenth of a yard, is slipped on the counter and employed to measure the circumferential velocity of the shaft, pulley, or belt. A small plumb-bob is also included which

can be used as a seconds pendulum for giving the time. The instrument is provided with a handle so that it can be pressed against the revolving shaft, and the motion obtained drives a single worm that gears into a lower worm-wheel of 100 teeth, having a graduated disc. On the spindle of this wheel is a pinion of ten teeth gearing into a wheel of 100 teeth, the disc of which is also graduated, the total ratio being such that one revolution of the hundreds dial corresponds with 1,000 revs. of the shaft. The arm carrying the worm-wheel is hinged, so that the whole counter can be thrown out of action without removing it from the shaft, or the gear can be disengaged for bringing the dials to zero.

429. Counter. Contributed by W. Smith, Esq., 1876.
M.1444.

This is a counter, by Mr. Norton, for reciprocating motion, on the intermittent system. A pawl, mounted on the lever, drives a ratchet-wheel on the index spindle. The first small dial, showing figures through a hole, has on its spindle a ratchet-wheel driven by a cam on the index spindle; a single tooth on the first spindle drives intermittently a wheel of ten teeth on the second, and so on throughout the series, the uncertainty through the display of half figures being thus reduced.

430. Six-figure counter. Lent by Messrs. Schäffer and Budenberg, 1888. M.1906.

This is an instrument arranged for counting either reciprocating motions or revolutions; it contains a vibrating lever, to which motion may be given direct, and also a crank by which the lever may be vibrated when it is desired to count revolutions. A toothed wheel on the spindle of the dial containing the unit figures is driven by the lever by means of a movement very similar to the escapement of a clock reversed. Another wheel on the same spindle, having one tooth only, drives intermittently a wheel with ten teeth on the spindle of the tens dial, and so on throughout the series.

431. Revolution counter. Lent by Messrs. W. H. Bailey and Co., 1888. M.1946.

This is a counter for working with a reciprocating motion. A pawl on the lever works into a ratchet-wheel on the spindle of the centre index, which records units and tens on the principal dial. The smaller dials give the higher multiples up to tens of millions. It is a suitable form of instrument for fixing like a clock to an engine-house wall.

432. Revolution counter. Lent by Messrs. Trier Bros., 1888. M.1894.

This is a five-figure counter on the intermittent system, patented by Mr. A. Kaiser in 1883.

The figures are placed on the peripheries of wheels, and the movement of the unit figure wheel is effected, as in Watt's and many other counters, by a reversed escapement; a crank-pin engaging with a slotted lever secured to the pallets imparts the necessary reciprocating

motion to the latter. A single tooth attached to the axis of the first wheel drives, intermittently, a wheel with ten projecting teeth, and so on throughout the series. Each of the figured wheels is locked during the intervals between the step movements by a projecting rim, on the preceding driving wheel, passing between the overhanging teeth.

Measurement of Length.

433. End measuring instrument, by James Watt. Watt Collection, 1876. Plate IX., No. 4. M.1814.

The principle of this instrument is the same as that employed in the most accurate of modern measuring machines.

There are two jaws, one fixed to a slide, and the other movable by a fine threaded screw. A pointer attached to the screw registers on a graduated dial fractions of a revolution, and a pinion working into the screw records the number of complete turns.

434. Micrometer. Maudslay Collection. Received 1900. M.3118.

This end-measuring machine was made early in the 19th century by Henry Maudslay while engaged in his labours in the development of accurate machine tools. As Sir Joseph Whitworth was employed for some years in Maudslay's works, it is probable that the further refinements he introduced in mechanical measurement were to some extent due to this same instrument.

The micrometer consists of a gun-metal bed on which slide two saddles fitted with end-measuring faces, and also having bevel-edged slots through which graduations on the bed can be read. One of the saddles extends through the bed and forms a split nut that, by set screws, can be delicately tightened upon a horizontal leading screw of 100 threads to the inch. This screw has a collar on it that is held against a stationary abutment, beneath the bed, by a plate adjusted by screws, so as to eliminate end play. The end of the leading screw has a milled head with a graduated edge of 10 divisions each subdivided into 10, so that each subdivision indicates a displacement of the saddle through ·0001 inch.

435. Whitworth's workshop measuring machine. Made by Messrs. Sir J. Whitworth and Co., 1871. M.1671.

The celebrated millionth measuring machine shown by Sir Joseph Whitworth at the 1851 Exhibition is so sensitive as to be unsuited for ordinary workshop use, so the form here shown, in which the graduations correspond with an alteration in length of ·0001 in., is that generally preferred.

The machine has a cast iron bed and two headstocks resembling the loose headstocks of a lathe, but instead of pointed centres each head has a flat one. One headstock is fast, while the other is movable along the bed by a quick pitched bed-screw, and its centre or measuring end is adjustable by a screw within the headstock. The fast headstock has its measuring end moved by a screw of 20 threads to the inch, and to

this screw is attached a wheel whose circumference is divided into 500 divisions. In using the machine for workshop purposes, it is usual to set the heads by placing between them a standard gauge of as near the required dimensions as is available, and then to fix the final position of the measuring ends by moving one end through the required difference by means of the divisions on the wheel.

436. Metric gauges. Presented by Mons. F. Pétrément, 1862. M.1669.

These are steel discs with gauge notches cut in them for use in ascertaining the thickness of wire, sheets, etc. The steps rise by tenths or hundredths of a millimetre.

437. Workshop gauges. Lent by the Newall Engineering Co., 1907. M.3477–9.

These gauges are of the type used in the interchangeable production of machine parts wherein a definite departure from standard size either way is permitted.

The " limit " of accuracy is determined by the different sizes of the two ends of the gauge, one end of which will " go " and the other " not go." The allowable departure from standard size, depending on the class of work produced, and also whether the fit is to be running, pushing or driving, is standardised as shown on the adjoining cards and not left to the judgment of the workman as in the older method. A 1·5 in.-diam. internal plug gauge, a 1·5 in. external gauge, a 1·5 in. and a 4 in. double setting bar illustrate this.

In the adjustable external limit gauge shown, which was patented by Mr. J. W. Newall in 1902, the usefulness of such gauges is greatly increased by having one of each pair of measuring anvils on the crescent-shaped casting screwed for adjustment. These are first set, by the standard setting bar shown or otherwise, and then an index forced into one anvil and a dial into the other. The anvil with the dial is turned till the desired higher limit is read off and is then clamped; the dial and index are interchanged and the other anvil set to the lower limit. This gauge will take sizes between 3·5 in. and 4 in.

In the internal micrometer, which was patented in 1902 by Mr. J. E. Storey, three legs at 120 deg. to one another have anvils at the outer ends and are bevelled at the inner ends to suit a bevelled axial micrometer screw arranged with a milled head and sleeve for direct reading to ·001 in. This gauge will take sizes from 5 in. to 5·5 in.

Measurement of Volume.

438. Siemens water meter. Contributed by Sir C. W. Siemens, 1858. M.166.

This form of rotary meter was patented by Sir C. W. Siemens in 1852; it is of the inferential class, in which the passage of the water causes a fan to revolve and so give a reading, from which the quantity is deduced by the results of previous experiments.

The meter shown is arranged as a short length of pipe, on the side of which is a case containing a counter with six dials. Within the pipe

are two cylindrical drums provided with helical blades, those of the first drum being right-handed and those of the other, left; so that as water flows through the pipe these two drums revolve in opposite directions; they are, however, geared together and also to the counter. At each end of the pipe and beyond the drums is a pointed block, fixed by three ribs and so arranged as to give a parallel flow to the water. The instrument is graduated by noting the readings after a known quantity of water has passed.

439. Siemens and Adamson water meter. Contributed by Sir C. W. Siemens, 1858, and Messrs. Guest and Chrimes, 1862. M.167 and 872.

This form of inferential meter was patented by Messrs. Siemens and Adamson in 1853; it is designed to reduce the amount of water that may, in the earlier form (*see* No. 438), be passed without the indicating mechanism moving. The measurement is performed by a reaction wheel or Barker's mill, the revolutions of which are practically proportional to the velocity of the water through the orifices. This instrument has been most extensively adopted and is known as the Siemens' meter.

In the sectional example shown, which is of a meter for a 1 in. pipe, the water before entering the casing passes through a strainer, it then reaches a fixed central pipe, down which it passes into the hollow centre of the revolving wheel, which in the example discharges it in six jets. The axle of the wheel is hollow below, and rests on a pivot, while the upper end is provided with a worm which gears into the counting mechanism above. The counter has two steps of worm gearing, as well as a differential arrangement involving a moving dial; there are two indicating fingers and a stationary pointer.

The re-action wheel of a much larger meter of this type is also shown.

440. Water meter. Presented by J. A. Müller, Esq., 1886. M.1842.

This water-meter is an apparatus for measuring the quantity of water passing by recording its speed. The water passes through a circular water-tight chamber, in which is a closed drum capable of revolving very freely, carrying two magnets extending across its top surface. The water, being deflected to one side of the drum, causes it to rotate by surface friction at a speed proportional to the speed of the water. In a dry chamber above the drum are two armatures attached to a light vertical shaft. As the drum and its magnets revolve in the water chamber, the armature revolves outside, and the armature shaft gives motion to the recording mechanism. The index and dials record the quantity in litres.

441. Tylor's rotary water meter. Lent by Messrs. J. Tylor and Sons, 1890. M.2333.

This is an inferential meter, the quantity of water passed being determined by the number of revolutions made by a fan carried round by the flowing water. The fan or panel with radial blades is placed with its axis vertical in a cylindrical casing into which the water enters by tangential openings and escapes axially. The entering water drives

round the fan at a speed proportional to its velocity, and the number of revolutions is indicated by a counter at the top of the instrument connected by worm gearing with the axis of the fan. A sectional drawing shows the construction.

442. Sporton's water meter (working). Presented by H. H. Sporton, Esq., 1901. M.2544.

This is a sectioned example of an inferential meter introduced by Mr. Sporton about 1885. It consists of a cylindrical casing with the usual counting mechanism above, while the water is admitted from a side pipe, fitted with a strainer, and delivered into a chamber at the bottom of the casing, from which it issues in inclined tangential jets, of circular section. These strike against the inclined vanes of a six-armed fan whose vertical axis extends upward, through a stuffing box to the counter; the water after acting on the fan passes, by an opposite side pipe, to the consumer. The specimen shown is for a pipe ·5 in. diam.; it has a capacity of 600 gals. per hour.

In a later form of this meter an arrangement was introduced to insure movement of the fan when only small quantities of water were passing. This consisted of a spring-loaded valve which, when the demand was so small as to cause but a slight difference of pressure between the supply pipe and the meter, remained closed, a few specially inclined holes near the periphery alone remaining open, through which the water issued with sufficient velocity to move the fan.

443. Frost's water meter (working). Contributed by B. Fothergill, Esq., 1862. M.727.

This meter was patented by Messrs. Chadwick and Frost in 1857. It consists of a vertical cylinder 4·6 in. diam. by 2·2 in. stroke, fitted with a cup-leather-packed piston. The piston-rod extends upward into a valve chest and is provided with two tappets for moving the valve gear and also with a pawl for rotating the counter. The valve gear consists of two horizontal slide valves one on the other. The upper or auxiliary valve is moved by the tappets on the piston-rod through a bell-crank lever, and lets water to and from two small cylinders that contain pistons attached to the lower or main slide valve that distributes the water to the large measuring cylinder below.

444. Hannah's water meter. Contributed by Messrs. Elgood and Co., 1874. M.1323.

This water meter, patented by Mr. S. Hannah in 1868, is an apparatus for recording by actual measurement the quantity of water passing, the unit of measurement being the volume swept through by a piston, working in a curved cylinder of such a length that the ends nearly meet, the space between the ends being occupied by two curved valve chambers concentric with the cylinder. The curved piston is without rod or other appendage, and at each end of its stroke strikes against and moves a small three-ported slide valve which controls the pressure of water acting on two small pistons attached to the main three-ported slide valve, which controls the admission and exhaust of water for the main piston. The piston, at each end of its stroke, also moves a lever connected with the recording apparatus.

445. Kennedy's water meter (working). Lent by Kennedy's Water Meter Co., 1890. M.2303.

In this positive meter, patented by Mr. T. Kennedy in 1852, the measurement is made by registering the number of times that a cylinder of known volume is filled and emptied, by the water passing through the meter.

The vertical measuring cylinder is provided with a piston kept tight by a rubber ring, which rolls between the surface of the cylinder and the bottom of the wide groove in the piston, so avoiding sliding friction. The upper end of the piston-rod is provided with a rack which rotates a pinion connected with the counter and with the valve gear. The pinion carries an arm which catches the haft of a swinging hammer; the arm lifts the hammer until it has passed its centre, when the hammer falls over by gravity and strikes a finger connected with the valve gear and so reverses the motion of the piston, and similarly on the return stroke. The swinging hammer prevents the valve from stopping in its mid position. A buffer is provided which absorbs any surplus energy in the hammer.

446. Frager's water meter. Presented by Prof. H. J. Spooner, 1896. M.2945.

This construction of positive meter was patented by MM. C. Michel and A. Frager in 1878, and subsequently improved. The water on entering passes through a strainer and is then distributed by two short D-slide valves to the ends of a pair of vertical cylinders with cup-leather packed pistons. There is a central trunk in each piston which acts as a tappet to a rod within it that moves the valve of the other cylinder just as in a duplex pumping engine. The counter is worked by a tappet on one of the rods.

447. Frager's water meter. Presented by the British Meter Co., 1904. M.3367.

This is a sectioned example of a later form of the meter described in No. 446, and differs from it only in details of construction. The pistons have cage-shaped extensions which make them sufficiently long to be self-guiding, and also enable them to act as tappets for the valve rod. Instead of cup leathers for the pistons, packing rings are used, and springs are employed to maintain the slide valves in close contact with their faces. The meter shown is for a ·5 in. pipe, and registers in tenths up to 1,000,000 gallons before repeating.

448. Working model of Dick's water meter. (Scale 1 : 4.) Lent by F. W. Dick, Esq., 1893. M.2656.

This represents a positive meter of the piston type introduced in 1886. The actual meter has four cylinders arranged radially, with each pair of opposite pistons connected by a bar with a square hole in it. In this hole fits a smaller square, formed on the back of a square slide valve working on a flat face in the centre of the machine. In this face is a central exhaust port and four admission ports. Each admission port communicates with the end of one of the four cylinders. The supply water enters the central space and presses on the four

pistons, but the slide valve puts the ends of two of the opposite pistons in communication with the supply and discharge respectively, so causing a stroke to be made, and this movement carries the slide valve into the position that causes a stroke of the two pistons at right angles to the former pair. The arrangement is a simple way of forming a duplex engine, as one slide valve by its motion in two directions answers for both. The quantity of water passed is recorded by a counter rotated by a star wheel driven by two pins attached to one of the reciprocating bars, but this detail is not shown in the model.

449. Tylor's water meter (working). Lent by Messrs. J. Tylor and Sons, 1891. M.2365.

In this meter, patented by Mr. J. J. Tylor in 1888, the water is measured by two double-acting horizontal cylinders, each provided with a long double piston so that the valve gear can be arranged between its two heads. The upper cylinder has a stroke equal to its diameter, while the lower one although of the same diameter, has a very short stroke, its main purpose being to actuate the valve of the upper cylinder. At the back of the machine is a cover carrying two slide valves, the upper valve communicating with the ends of the lower cylinder and the exhaust or discharge pipe, while the lower valve similarly acts for the upper cylinder. The water enters the machine at the base of the central case and leaves through the discharge pipe in the back cover. When the upper piston has nearly completed a stroke in one direction it moves the upper slide valve, thereby causing the lower piston to make a stroke, and in so doing this piston moves the lower slide valve which accordingly causes the upper piston to make a return stroke, and so on, each piston moving the slide valve controlling the other. The pistons are packed with bucket leathers and are made as light as possible, but buffers on the cylinder covers are provided to stop them at the ends of the stroke. The counter at the top of the case is driven by gearing receiving motion from a ratchet worked by the upper piston.

450. Kent's water meter (working). Lent by G. Kent, Esq., 1890. M.2345.

In this positive meter, patented by Mr. W. G. Kent in 1889, the measurement is made by registering the number of revolutions performed by a kind of rotary engine through which the water passes. In a nearly cylindrical chamber is placed an elliptical vulcanite piston capable of a combined sliding and rotating motion round a roller fixed eccentrically in the casing. This roller fits a long slot in the body of the piston, and the measuring volume of the machine includes the unoccupied portion of this slot as well as the space swept by the piston. After passing through a conical strainer in the base of the meter the water enters the measuring case through a port on one side and escapes by the opposite port, the piston acting as the slide valve. The motion of the piston is transmitted to a counter fixed at the top of the meter. Owing to the small weight of the vulcanite piston but little frictional resistance is offered, and no appreciable loss of pressure is sustained by the water in passing through the machine. The example, which is shown in parts, is for ·375 in. pipes, passes 800 gals. per hour, and will work with a head of 1 in.

451. Positive water meter (working). Lent by Messrs. Beck and Co., 1902. M.3230.

This meter, which measures by registering the number of times that three single-acting cylinders are filled by the water passed, was patented in 1894 by Mr. W. A. G. Schönheyder, and is a development of a meter made ten years earlier in which three horizontal cylinders were used.

The water is admitted through a perforated strainer, to the upper chamber of the meter, which in the explanatory example shown is formed by a glass cover. The floor of this chamber contains three vertical cylinders, arranged round a central distributing valve which rolls on a hemispherical seating, through ports in which the water passes to and from the lower ends of the cylinders, and thence by an axial passage into the outlet pipe. This cup-shaped valve has three projecting arms or crossheads, provided with suitable bushes to receive the spherical ends of the piston rods, the piston cups giving sufficient play to permit of a slight deviation from the vertical. In this way the valve is rocked on its spherical seating as the three pistons successively descend, rotation being prevented by projections on the valve which engage in notches on the seating, and the stroke limited by a central collar which restricts the downward movement of each piston. The valve, piston rods, and cylinders are of gunmetal, the valve seating and bushes of vulcanite, and the piston cups of hardened india-rubber. The counting mechanism, which is not shown, is contained in the top cover and driven by a pin projecting from the top of the valve.

The size represented is for ·25 in. diam. pipe with a maximum delivery of 100 gals. per hour, but under a pressure difference of 50 lbs. it will pass 250 gals. per hour.

452. Water meter. Presented by J. Bernays, Esq., 1906. M.3442.

This construction of positive meter was patented by Mr. Bernays in 1895. It consists of a casting having four horizontal cylinders arranged radially, with each pair of opposite pistons rigidly connected by a flat rod. The centres of the two rods are connected by a short link which controls their movements, its middle point describing a circle round the intersection of the rods; this motion is utilised in driving the circular distributing valve. Four passages are formed in the lower part of the casting, one leading from the outer end of each cylinder to a flat valve face in the central space between them; the valve face has also a central exhaust port discharging below. The supply water enters the central space and presses on the four pistons, but the valve puts the ends of two of the opposite pistons in communication with the supply and discharge respectively, thus causing a stroke to be made, and this movement carries the valve into the position that allows the other pair of pistons to make a stroke. Webs are cast between the cylinders, forming a horizontal partition dividing the supply from the discharge. The outside of the casting is turned to a conical shape and fits into a conical casing which is closed by a cover carrying the counting mechanism, this being driven by a pin projecting from the upper piston rod. The cylinders have gun-metal liners and the pistons are packed with cup leathers. The action of this meter is similar to that of No. 448 adjacent.

453. Disc water meter. Presented by the British Meter Co., 1904. M.3368.

This is a sectioned example of a positive water meter embodying the principle of the disc engine shown in No. 99, in which a disc gyrating on a conical base within a spherical cavity provided with a fixed partition, becomes the equivalent of a piston in a cylinder.

In the meter the disc or piston is formed of vulcanite, and has a conical lower face which enables the bottom of the spherical chamber to be made flat. In every position of the disc it divides the chamber into receiving and discharging spaces and the water in the receiving space exerts a pressure on one side, while at the same time less pressure exists on the discharging side. The disc is thus caused to gyrate, and an amount of water is passed at each complete movement equal to the contents of the entire chamber. A rod, projecting upward from the ball forming the centre of the disc, travels in a fixed circular recess, and as it gyrates moves the counting mechanism.

The disc or piston acts as its own valve, its edge passing over openings in the spherical wall of the chamber so situated that they admit and discharge the water at the right portions of the cycle. The water enters the lower part of the meter, then passes through the side wall of the chamber, through the chamber itself, into the upper portion of the case and thence out through the side passage.

The example shown is for a ·5 in. pipe, and it registers by tenths up to one million gallons before repeating.

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454. Wet gas meter (working). Lent by Messrs. James Milne and Son, Ltd., 1905. M.3382.

This is a wet meter of an early type, made about the year 1827 by Messrs. James Milne and Son.

The meter consists of a cast-iron case, partly filled with water, containing a horizontal measuring drum capable of rotating on pivots. The drum is divided into four chambers by partitions set obliquely so that they cut the water, thus decreasing the resistance and rendering the motion more uniform. Each chamber is provided with an inlet and an outlet formed by extended passages which bring these openings diametrically opposite one another, thus when one inlet is open to gas the corresponding outlet is sealed by the water. The partitions stop short of the axis, allowing free passage of the water from one chamber to the other, but no gas can pass. The gas enters the meter through an axial pipe which acts as a support for one pivot of the drum, and passes into the upper part of a cylindrical chamber, forming an extension of the drum into which the gas inlets open. It then passes into those inlets which are above the surface of the water and exerts an unbalanced pressure, causing the drum to revolve until the outlets at the other end are raised above the water, when the gas is discharged into the casing and thence to the service pipe. This form of drum is attributed to Samuel Crosley, and it is, with slight modification in construction, that generally adopted in meters of this class. The volume of gas passed is measured by the number of times the chambers are filled, as registered by a counter driven by the drum. The height of the water is limited by the turned-up end of the gas inlet inside the drum to which an overflow pipe is fitted, fresh water being added through a pipe and funnel.

The top half of the casing has been replaced by a glass cover; lines are painted on the drum to indicate the chambers and passages.

455. Wet gas meter. Presented by Messrs. Bischoff, Brown and Co., 1862. M.889.

This meter was patented in 1858 by Mr. S. Clegg, one of the pioneers of gas lighting, who in 1807 introduced the first wet gas meter.

The exterior case, of which a portion has been removed, is partially filled with water and contains a horizontal drum, capable of rotation and provided with five external spiral chambers, the small ends of which open into it and the large ones outside. The gas enters the meter by the vertical pipe seen, and, after passing through a non-return valve, reaches the interior of the drum, whence it flows into one of the spiral chambers and so exerts an unbalanced pressure which causes that chamber to rise out of the water till its inner end is again closed by immersion. The next chamber then acts in rotating the drum, and the gas in the former one is discharged above the surface of the water and thence to the service pipe, the volume of gas passed being measured by the number of times the chambers are filled, as registered by a counter driven by the drum. As it is essential for accurate measurements that the immersion of the drum should be constant, its bearings are in this meter carried in a swinging frame controlled by a bell float.

456. Wet gas meters. Contributed by Messrs. W. and B. Cowan, 1873. M.858, B., C., & D.

These embody arrangements patented in 1858–63 by Messrs. Esson and Cowan, for insuring constancy in the level of the water in which the rotating measuring drum is immersed, and also for preventing the passage of gas should the water be withdrawn.

The outer case, containing the drum, has attached to its front a rectangular chamber provided with a regulating valve and a vertical diaphragm. The gas enters a compartment serving as a saturating chamber before passing to the interior of the measuring drum, to be registered as it causes the drum to revolve, and there is a regulating valve connected with a hollow metallic float which closes it should the water in the meter get too low; for the purpose of further maintaining the correct immersion a reserve supply of water is contained in an additional chamber within the casing.

In one example there is a notched overflow pipe from the drum chamber into a waste chamber below; a fitting is also shown for adding to a meter, which will close the outlet pipe, by a water seal, should the apparatus be placed out of level.

457. Wet gas meter. Contributed by W. H. Moran, Esq., 1862. M.728.

This meter, patented in 1861 by Mr. Moran, chiefly differs from others of its class in the device for maintaining the water level; this consists in the addition, to the axle of the rotating measuring drum, of a disc with projections acting on a scoop which bales water from a reservoir into the drum chamber, thus maintaining it at the level of an overflow notch.

458. Dry gas meters (one working). Lent by Messrs. G. Glover and Co., 1887. M.1860–1.

Gas meters of the bellows class, containing no water, are a more recent invention than wet ones, having been first introduced in 1820 by Mr. John Malam.

In the example shown, which has glass sides, the upper compartment is that into which the gas enters; thence it passes through ports, alternately opened and closed by two slide valves, down into the two circular measuring bellows which are attached to a central partition dividing the lower portion of the casing into two compartments. When gas is inflating one of the bellows, it is also entering the opposite compartment and so collapsing the other bellows from which it passes by the exhaust port of its slide valve into the service pipe; at the same time, gas from outside the bellows which are being inflated is, by the other slide valve, also passing into the service pipe. Uniformity of stroke is secured by connecting the pistons with a crank-pin, from which mechanism the slide valves and the counting apparatus are driven. Each of the bellows is double-acting and the whole arrangement resembles a pair of oppositely inclined diagonal steam cylinders acting on a single crank, the revolutions of which are registered as a measurement of the amount of fluid passed. The examples shown have improvements patented by Mr. Glover in 1863, including the addition of a pawl which prevents the meter being worked in a wrong direction.

459. Dry gas meters (one working). Contributed by Messrs. W. and B. Cowan, 1873. M.858 and 858A.

These contain improvements patented in 1870, but the general construction is similar to that in the preceding example. The leather of each bellows is secured at its inner circumference to its piston, while the outer circumference is held by a fixed diaphragm having a corresponding hole in it, so that each piston can pass through its diaphragm, thus lengthening its stroke; between these two diaphragms is a partition completely dividing the bellows chambers.

In the working of dry meters the non-oxidising properties of illuminating gas prevent the destruction of the prepared leather, and for this reason these meters are usually kept full of gas after being tested.

460. Experimental wet gas meter. Received 1900. M.3133.

This meter is constructed to show the rate of consumption, as well as the volume of gas which has been consumed. The quantity of gas passed is measured by the rotation of a four-chambered drum partly immersed in water, and there is an arrangement for preserving the water level similar to that in No. 456.

Above the drum is a clock, the long hand of which revolves once a minute round a large dial fitted with another hand worked by the drum and therefore registering the amount of gas passing. Two smaller dials show time in minutes and volume in fractions of a cub. ft.

461. Prepayment gas meter. Presented by Messrs. Sawer and Purves, 1897. M.3004.

This is a dry meter fitted with an arrangement patented by Messrs. Sawer and Purves in 1891–94, by which the quantity of gas delivered

by the meter is determined by the number of pennies previously placed in the slot. It is thus a measuring machine that delivers gas equivalent to the money received, while also acting as an ordinary recording meter.

The example is fitted with glass panels through which the mechanism is visible. Below is the usual double bellows of a dry meter, while above is the mechanism that shuts off the gas after the amount paid for has been delivered; on the left side is a locked box in which the coins received collect.

A projecting handle is connected with a grooved drum inside; when a penny-piece is placed in the payment slot above, the coin drops into the groove, but projects from the face of the drum so as to act as a driving pawl, until a half-revolution has been performed when the coin tumbles into a locked box, the coin thus acting as the driving pawl for power transmitted from the external handle. Each half-revolution rotates a quick pitched screw, on which is a nut that turns on the gas; this nut is formed as a spur wheel and is geared to the mechanism, so that as the gas passes the nut is rotated and thus slowly moved backward until it neutralises the motion given by the screw and again turns off the gas. If several coins are inserted the resulting motion of the screw is greater, and consequently the meter works longer before this motion is again neutralised. The arrangement of differential gear resembles that used in some forms of steam steering gear. The amount of gas paid for, but still unconsumed, is shown by an index attached to the nut.

462. Wet gas meter. Lent by George Wilson, Esq., 1905. M.3394.

This is a wet meter of the ordinary type, fitted with appliances for preventing fraud by disturbing the water level.

It consists of a cylindrical case containing a measuring drum partly immersed in water. The drum is of the form designed by Mr. S. Crosley about 1821 and afterwards slightly improved in construction; it has oblique internal radial partitions stopping short of the axis, and forming, with the end plates, four chambers. The inlets are at the front end under a cover and the outlets at the back placed about 180 deg. behind them, so that each outlet rises from the water just after the corresponding inlet has been closed. The gas enters those measuring chambers whose inlets are above the surface of the water and exerts an unbalanced pressure which causes the drum to rotate until the outlets are raised above the water, when the gas is discharged to the service pipe. To the front of the case is attached a rectangular chamber communicating with it below the water level, and the gas enters the meter at the top of this chamber through a valve which is attached to a float; when the water level falls, by evaporation or otherwise, beyond a certain amount, the valve closes and cuts off the gas. More water must then be added through the guarded orifice provided, the correct height being fixed by an overflow pipe through which any excess passes into the waste box below, whence it may be drawn by a water-sealed pipe. The gas passes from the front chamber by a vertical pipe having its mouth above the water and a branch leading through a water-sealed orifice to the space under the drum cover. The motion of the drum is transmitted, by worm gearing and a vertical shaft, to the counting mechanism on the top of the front chamber.

The meter has a capacity of 30 cub. ft. per hour when making 2 revs. per min. This specimen is fitted with glass panels to show the construction.

Measurement of Mass.

463. Early counter weighing machine. Received 1903. M.3283.

Scales or balances of the equal-armed pan type are of unknown antiquity, and the unequal-armed construction, represented by the steelyard, was also in use by the Romans; the application of compound levers, as in the modern platform weighing machine, is, however, much later and appears to have been first made about 1743 by John Wyatt at Birmingham.

The machine shown is of uncertain date, but is believed to have been made in the 18th century and it somewhat resembles Wyatt's arrangement. The scale pan is in the form of a platform, giving unlimited vertical and lateral space for the object being weighed; beneath it at one end is a steelyard with its fulcrum extended as a shaft, so that the knife-edges at its ends are sufficiently separated to give lateral stability. Above the steelyard is an equal-armed balance beam by which some of the weight of the platform is transmitted, as an upward pull, to one side of the steelyard, while the remainder of the weight acts directly downward upon the steelyard by two knife-edges at the same leverage on the other side of the fulcrum. As the platform is supported on three edges which have equal vertical motions, it is steady and remains horizontal.

The long arm of the steelyard is graduated by side pegs into eight divisions, each equal to the short arm of the lever so that a pound weight hung on these will weigh up to 8 lbs. (*i.e.* a butcher's stone) on the platform.

464. Coin balance. Presented by John Dickinson, Esq., 1905. M.3392.

This is for weighing gold in single coins; it is by the same maker as the one beside it (No. 465) and dates probably from the beginning of the 19th century. As business was carried on in those days principally by cash payments it was convenient to have a balance in a portable form. The balance has a scale beam with two pans; the one for carrying the different weights (now missing) has a support which is required when no coin is on the opposite pan; the stand for the beam is incorporated with the hinge of the mahogany case so as to follow the lid when being closed, care being taken to fold back the scale pans on the beam.

465. Guinea balance. Made by A. Wilkinson. Received 1905. M.3391.

This is a form of equal-armed balance for weighing guineas or half guineas, one by one, and giving the value of the excess or deficiency directly in pence; it must have been made anterior to 1817, when the guinea ceased to be coined.

The balance is of the same general construction as the one beside it (No. 464), but the weight is attached directly to the scale beam by a pin so that it can be turned over. In one position it balances the weight of a guinea and in the other that of half a guinea. The beam on the other side of the fulcrum is fitted with a rider and is graduated so that the deficiency in weight can be read directly in pence up to 12 and the excess in farthings up to 5. The knife edges are triangular in shape on bearings of hardened steel. Printed instructions are pasted inside the case.

466. Coin balance. Received 1907. M.3481.

This is an equal-armed balance with hanging scale pans, and has steel knife edges in a steel beam with Dutch ends and brass pans suspended by plaited silk cord.

It is intended for the purpose of weighing gold coins. The third great recoinage of gold in England took place in 1772–4, and of the two sets of brass weights shown one gives the lowest legal tender for coins minted prior to January 1st, 1772, and the other subsequent to that date.

The weights are for guineas, half guineas, and quarter guineas; the last named pieces were first coined in the reign of George I., and they were again coined in that of George III., but were soon discontinued on account of their small size; one-third guinea pieces were also coined.

467. Coin balance. Presented by H. R. H. Southam, Esq., 1905. M.3401.

This is a portable folding balance closely resembling No. 465, but in this case there are spaces for the loose weights, of which there have been five, but only three are left; these are for the guinea, the sovereign and the half-sovereign, so that the balance must date subsequently to 1817, when the sovereign was first coined. The slotted hole probably contained a gauge for giving the correct thickness and diameter of the coins.

468. Mancur's spring balance. Presented by H. W. Dickinson, Esq., 1905. M.3398.

This is perhaps the simplest application of the elastic extension of a spring to the purpose of weighing. A plate spring of tapering section is bent to an elliptical form with the ends overlapping; a pointer hinged to one end passes through a slot in the other. When a weight is suspended from the spring the ends tend to separate, causing the pointer to move over a graduated scale which is fixed to the neutral part of the spring. By adopting two different positions for the suspending hooks a large range can be obtained, the reading being from zero to 32 lbs. rising by 1 lb. on one side of the scale, and from 20 lbs. to 300 lbs. rising by 30 lbs. with further sub-division to 5 lbs. on the other.

The balance is intended for household use, but as the accuracy is only about 1 in 100 it has been largely displaced by other forms in which a helical spring is used.

469. Coin-weighing machine. Received 1883. M.1674.

This is a simplified form of the machine used at the Royal Mint for separating the new coins into three classes, determined by their weight.

Each coin is automatically placed on the weighing beam and then passed into the "heavy," "standard," or "light" compartments according to the position taken up by the beam. The various motions for feeding the coin, lifting the beam, and swinging the distributing shoot, are given by three cams.

470. Grain-weighing machine. (Scale 1: 4.) Presented by W. H. Baxter, Esq., 1881. M.1508.

This is an automatic machine, patented by Mr. Baxter in 1869–80, for weighing brewers malt and recording the duty payable; it was to be placed in a locked enclosure so situated that all malt, on its way to the rolls, must pass through it.

The malt is delivered, by an overhead shoot, into a cylindrical drum, carried on trunnions hanging on knife edges on a scale beam; when the drum end of the beam descends sufficiently, a lock retaining the drum is released and at the same time the supply of grain is shut off, while a wheel on the trunnion comes into gear with a pinion continuously rotated by power, so that the measuring drum is quietly emptied. It then completes its revolution and rises to the charging position; in so doing turning on the supply of grain and moving a counting apparatus, the dials of which indicate the amount of the tax to be paid in £ s. d.

The cup elevator, or "Jacob's ladder," shown was added to facilitate experiments with the model.

471. Registering weighing machine and sectional drawing. Lent by Messrs. W. and T. Avery, 1891. M.2367.

The action of the weight on the platform is transmitted to the upper steelyard by the usual arrangement of compound levers, and the measurement is performed by sliding a constant weight along the graduated arm, which is notched at intervals equivalent to quarter-hundredweights. The odd pounds are determined by sliding a lighter weight, which is in the form of a bar, until the exact equilibrium is established, when the position of this bar as read by its scale indicates these odd pounds. The machine weighs up to 10 cwt.

To register the weight the machine is fitted with an arrangement by which the reading in cwts., qrs., lbs. is printed on a cardboard ticket. The ticket is placed face downward in a slot above which is a lever and cam by which it can be pressed upon the steel type immediately below it. This type is in the form of two long strips, connected, the wider one with the large sliding weight, and the other with the sliding bar. The type which is on the upper face of the wide strip is so spaced that the figures under the ticket shall correspond with the cwts. and qrs. of the load, while the narrow one gives the lbs. By these arrangements no loose weights are required, and the tickets are correctly stamped without any index readings having to be made. The slot carrying the ticket admits of a slight lateral movement by which two weights representing the gross and tare can be printed on the same ticket in a convenient position for subtraction.

472. Duckham's hydrostatic weighing machine. Lent by the East Ferry Road Engineering Works Co., 1891. M.2376.

This machine consists of a cylinder carried by an iron strap by which it can be suspended from a crane-hook. Within the cylinder is a

leather-packed piston, the rod of which passes through a leather-collar at the bottom of the cylinder, and is provided with a hook from which the mass to be weighed is suspended. The cylinder is full of oil, and communicates with a gauge attached to its front, by which the pressure on the oil is measured, the dial being so divided as to indicate directly the weight lifted. By slightly rotating the suspended load the friction of the packing is practically eliminated. The example is for dealing with weights up to one ton.

MEASUREMENT OF VELOCITY.

473. Speed indicator and recorder for railway trains. Contributed by Mrs. W. A. Brown, 1891. M.2398.

This machine was patented in 1863 by Mr. W. A. Brown, but to some extent the invention was anticipated by an instrument devised about 1846 by Mr. W. Ricardo. Its object is to obtain a diagram of the speeds of a train throughout its journey, and also particulars of the various stoppages. This is drawn upon a ribbon of metallic paper, which is passed between rollers at a constant rate by clockwork, whilst a marker is moved across it at a speed proportional to that of the train. In this way a continuous time-distance line is drawn, which is parallel to the direction of motion of the paper when the train is at rest, and inclined when the train is moving; the tangent of the angle of inclination being proportional to the speed.

In the instrument shown the motion of one of the train wheels is communicated to the pulley at the side of the box containing the apparatus. This pulley makes about 220 revs. for every mile travelled, and communicates motion to a traversing screw carrying a nut to which the marker is attached; the marker moves through 1 in. for every 2·25 miles travelled, and the paper advances at the rate of 1 in. in 10 minutes. At the right-hand side of the instrument is a reversing clutch by which the movement of the pencil is automatically and rapidly reversed before the marker reaches the edge of the paper, so that a diagram of indefinite length can be taken.

In the diagram appended, which records a journey of about 78 miles on the London, Chatham and Dover line from Victoria Station to Dover Harbour, the intervals between the transverse lines correspond to minutes. The speed of the train at any instant, which is indicated by the slope of the recording line, can be read directly by means of a specially graduated protractor. It will be seen that the greatest speed was attained between Selling (S L) and Canterbury (C Y), and was 46 miles per hour. Where the train was at rest the recording line is perpendicular to the transverse lines, the lengths of such parts giving the durations of the stoppages; thus at Clapham and Brixton the train stopped for ·5 and 1 minute respectively, whilst at Herne Hill the direction of slope of the line is reversed for a short distance, indicating that the train was backed about 100 yds., just after entering the station.

474. Speed indicator. Lent by H. Faija., Esq., 1876. M.1427.

This "motometer," patented by Mr. A. Barlow in 1875, is designed to show on a dial the speed of a revolving shaft, in revolutions per

min.; it differs from most appliances of the class in that it is a combination of a clock and a counter, and gives a result that has been averaged over a definite interval.

The speed is shown by a pointer, carried loosely on a sleeve, which forms part of a clutch and is driven from a clock train at the rate of one turn per min. The clutch is released momentarily by ratchet gearing, driven from the shaft whose speed is to be observed, and so arranged that the clockwork steadily moves the pointer sleeve while the shaft makes 200 revolutions and then releases it, so that the distance thus travelled by the pointer is greater the lower the speed of the shaft. The pointer and sleeve are, by springs, continually tending to fly back to the starting position when released, and the pointer is also fitted with a brake which retains it over its last reading till it is momentarily released, to permit of its moving into the fresh position should the speed have altered during the last interval.

In another and more obvious form of the instrument, the shaft drives the clutch and pointer, while the clockwork releases the clutch at intervals of one minute, the pointer being, however, retained at its last reading as above until the end of the fresh minute.

475. Speed recorder for trains. Lent by Messrs. Elliott Bros., 1862. M.343.

This apparatus is intended for recording on paper the speed at which a train is running. Motion taken from one of the axles would cause the vertical spindle to revolve, tending to carry the fan with it; the resistance of the air would cause the fan to mount the thread of the screw, more or less, according to the speed. The rise and fall of the fan, communicated to a pencil bearing against the paper on the revolving drum, would record the variations in speed. Hick's engine governor of 1840 (*see* No. 218) has a similar mechanism.

476. Speed indicator. Lent by J. Ramsbottom, Esq., 1890. M.2310.

This instrument, known as Ramsbottom's velocimeter, was devised in 1860 for indicating the speeds of engines while experimenting with the inventor's arrangement for supplying tenders with water while running (*see* No. 158).

The closed glass tube half filled with oil revolves on a vertical axis and was driven by a band from a sheave on the trailing axle of the locomotive. The depressed centre of the surface of the rotating oil when read by the graduated scale at the side of the tube, gives the speed of the engine in miles per hour; the amount of depression varies as the square of the speed. A sectional drawing is shown.

477. Drawing of Stroudley's speed indicator (Scale 1 : 3), 1904. Centrifugal pump. Lent by Messrs. Dewrance and Co., 1888. M.1922 and 1937.

This indicator, patented by Mr. W. Stroudley in 1879, consists of a tank containing water, from the bottom of which a tube connects it with the simple centrifugal pump with eccentric casing shown, which is actuated by a suitable working part of the engine. The rotation of the

pump wheel causes the water to rise in the glass tube in front of the graduated scale. For indicating the speed of locomotives, the motion is taken from one of the axles and the apparatus is so graduated that the scale indicates miles per hour. The scale can be adjusted, so as to compensate for any variation in the amount of water in the tank. Should the water rise beyond the top of the glass tube, it flows back into the tank by the tube at the back of the graduated scale.

478. Hedges speed indicator. Received 1890. M.2314.

This instrument by Mr. K. Hedges closely resembles the velocimeter of Mr. Ramsbottom, No. 476, but is an improvement in that the depression of the parabolic cavity is directly proportional to the speed, so that the graduations of the scale are uniform and the range of the instrument is greatly increased. This difference is due to the top of the tube being closed by a flat cover and a much larger proportion of the tube being filled with liquid. When in use the diameter of the parabolic air cavity at the top is less than the diameter of the tube, and varies with the speed in such a manner that the vertex of the paraboloid sinks proportionately with the increase in the speed. A sliding sighting bar is attached to the case to assist in accurately determining the position of the vertex, the reading being taken on the fixed scale.

479. Speed indicator. Lent by Messrs. D. Napier and Son, 1892. M.2462.

In this instrument the speed is shown by the rise of a column of mercury in a fixed glass tube, the lower extremity of which is in communication with the circumference of a closed rotating cup of mercury, the centrifugal pressure of which is thus indicated.

The fixed support of the glass tube forms the framing of the machine, and carries the bearings of the rotating cup. The lower bearing is a footstep, and the upper one is formed by a boss projecting downwards into the mercury cup. The interior of this boss communicates with the glass tube, and also with a fixed tubular arm which reaches to the circumference of the rotating cup. The cup is about half filled with mercury, the rotation of which is insured by vanes provided inside the cup. A set of baffle rings is introduced to prevent the splashing out of the mercury round the upper bearing. For transport a screw on the footstep enables the top of the mercury cup to be forced against a leather washer attached to the framing, thus completely closing the receptacle. The scale is graduated experimentally, but the heights increase nearly as the square of the speed. A line on an ivory float on the top of the mercury column enables the scale to be easily read. A sectional drawing is shown on the label.

480. Speed indicator. Lent by Messrs. Elliott Bros., 1888. M.1889.

This form of speed of revolution indicator was patented in 1881 by Mr. D. Young.

It consists of a small centrifugal governor, loaded by a helical spring and enclosed in a case. When the spring is compressed, owing to the centrifugal tendency of the governor balls, the speed of rotation is

indicated in revolutions per minute by a finger connected with the spring by levers and toothed gearing, by which it is moved over a suitably graduated dial.

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481. Biram's anemometers. Made by Messrs. John Davis and Son, 1865 and 1882. M.1594–5.

Instruments measuring the velocity of air by the aid of a reversed windmill were first patented by Mr. B. Biram in 1842, but a somewhat similar arrangement had been proposed earlier.

The early example shown has a ten-bladed wheel 12 in. diam., built of copper, and provided with sails of oiled silk; the axle of the wheel carries a worm actuating a three-figure counter, and the velocity is determined from the difference between the readings at the commencement and close of an interval measured by a watch.

In the later example the wheel is arranged in a cylindrical shield 4 in. diam., and has aluminium blades, while the counter is secured above it, the connection between them being made by worm gear and a shaft which can be disengaged at will, so that the counting mechanism can be thrown into action for a minute or other interval and then released. The table and diagram for the correction at various speeds is attached.

482 Lowne's anemometer. Made by Messrs. John Davis and Son, 1882. M.1596.

This modification of the Biram anemometer is convenient in that the counter is horizontal and is directly carried by the stand on which the fan and its guard are supported. The wheel is 2·5 in. diam. and has eight aluminium vanes. The connection with the counter has the usual disengaging motion.

483. Dickinson's anemometer. Made by J. Casartelli, Esq., 1901. M.1597.

This instrument, introduced by Mr. Joseph Dickinson about 1850, determines the velocity of an air current from the deflection it causes to a swinging flap. The flap consists of a framed plate of mica, carried along its top edge between centres and fitted with a counterpoise, so that even a slight pressure on its surface shall cause an appreciable deflection. The centres are held in a square frame provided with a quadrant so graduated that the velocity of the air is indicated in feet per minute by the reading opposite the flap; a small spirit level is also attached to the framing to insure that it is vertical while an observation is being made. Like most other anemometers, it is experimentally graduated by attaching it to a long arm which is swept round horizontally at various speeds by mechanism.

484. Siphon gauges. Presented by J. Daglish, Esq., 1868. M.1592–3.

The two examples show water gauges used for measuring the differences of pressure involved in mine ventilation. Each consists of a U-tube partly filled with water and having one end open to the atmosphere but fitted with a contracted or protected orifice to exclude dust,

while the top of the other limb is connected by a tube with the upcast shaft, or other place where the pressure is to be investigated. The difference in the level of the water in the two tubes corresponds to the difference of pressure, and is read on a boxwood scale fitting between the two tubes and adjustable, so that its zero mark can be placed at the water level in one of the tubes. In the Daglish gauge the position of the scale is adjustable by a quick pitched screw, and a spirit level is added to insure the scale being vertical when read.

Measurement of Fluid Pressure.

485. Vacuum indicator, by James Watt. Watt Collection, 1876. Plate IX., No. 5. M.1816.

This simple instrument was no doubt at the root of the invention of the indicator for ascertaining the power of steam engines.

It consists of a small upright cylinder with a piston and rod, which is connected by a light chain with a rocking beam above, the other end of the beam being connected with the upper end of a helical spring, fastened at its lower end. The lower end of the cylinder is connected with the cylinder of the steam engine, the condenser, or other vessel in which the degree of vacuum is required to be ascertained, by a pipe or cock; on opening the cock, the piston is consequently forced down by the pressure of the atmosphere; a pointer on the beam gives a good indication of the degree of vacuum existing in the vessel or cylinder.

486. Pressure gauge. Presented by Messrs. Watney, Combe, Reid and Co., 1899. M.3075.

This steam gauge was attached to the cylinder jacket of a rotative beam engine supplied by Messrs. Boulton, Watt, and Co., in 1808, to Messrs. Reid's brewery, Clerkenwell. The boiler pressure was 5 lbs. above atmosphere, and this gauge represents the arrangement in general use till about 1850, when the continual increase in pressure led to the adoption of dial gauges.

The apparatus consists of an inverted siphon pipe of wrought iron, one extremity of which was provided with a flange, for attachment to the steam jacket or to the steam pipe, while the other was fitted with a socket which supported a glass tube that protected a light rod terminating in a cork disc. The siphon was half filled with mercury, so that when the steam pressure increased it caused the mercury to rise in the outer leg, and so lift the rod within the glass tube, thus indicating the pressure, usually upon a scale placed behind the tube. The tube was closed at the top, but was so fitted as not to seal the end of the siphon.

487. Vacuum gauge. Presented by Messrs. Watney, Combe, Reid and Co., 1899. M.3076.

This gauge, for indicating the degree of exhaustion of the condenser, was fitted to the same engine as the pressure gauge No. 486, the connection with the condenser being made by a considerable length of copper pipe. From this pipe a wrought-iron extension piece, ·375 in. external diameter, passed up through a small reservoir to the top of the closed end of a vertical barometer tube. The reservoir was open to the

atmosphere, and was filled with mercury, so that as the pressure within the condenser fell the mercury was forced up the barometer tube by the atmospheric pressure. The whole instrument is constructed within an iron casting mounted on wood; near the upper end of the exposed portion of the tube is a graduated scale for reading the difference between the pressure of the atmosphere and that within the condenser; this is given in inches of mercury, the graduations being so reduced that the reservoir correction is allowed for.

488. Pressure gauge. Presented by Messrs. Smith Bros. and Co., 1902. M.3256.

As boiler pressures increased, the mercury gauge originally used became very inconvenient, owing to the height of the column required, and locomotives were unprovided with any means of determining the steam pressure; in a few instances a form of thermometric gauge was adopted, but the usual practice was to rely upon the indications derived from the spring-loaded safety valve.

Mr. Sydney Smith, of Nottingham, was one of the earliest to produce a convenient form of mechanical pressure gauge, and this he patented in 1847, while in the same year he submitted it to George Stephenson, who at once had it tried on one of the boilers at his Tapton colliery. The gauge consisted of a diaphragm of vulcanised india-rubber held at its circumference between flanges which connected the two halves of a spherical chamber. The lower half of the chamber was in communication with the boiler, and the upper half supported a vertical dial, over which an index finger was moved by a rod, so connecting it with the centre of the diaphragm that it indicated in a greatly magnified manner the amount of bulging which the pressure was occasioning.

In 1854 Mr. Smith patented an improved form of this gauge, and the example shown, which was made about 1860 and was in use for 40 years, is of this later type. The diaphragm is still of vulcanised rubber, but it is loaded or reinforced by a close volute spring wound with such a camber that at the working pressure it is approximately flat. To the centre of the spring is secured a vertically-guided rack gearing into a pinion on the index spindle, as shown in the attached drawing.

489. Steam and vacuum gauge. Presented by Messrs. Mather and Platt, 1859. M.303.

This is a portion of a mercurial gauge patented in 1856 by Messrs. Mather and Millward. The scale is only 4 in. in length, but the range is up to 100 lbs. pressure, a result that is due to the use of a long mercurial stand-pipe of much smaller diameter than that of the glass tube. Steam admitted to the top tube forces the mercury up and then through the fine vertical stand-pipe that enters the tube at the bottom. Three-way cocks were introduced by which the gauge could be placed in communication with the condenser when required.

490. Pressure gauges. Contributed by J. Inshaw, Esq., 1862. M.365.

This arrangement of pressure gauge was patented by Mr. Inshaw in 1856. One of the gauges is probably the experimental instrument

and has its mechanism visible, but the other is a completed boiler fitting, closed in.

Two thin discs of sheet metal are connected at their edges so that steam or other fluid under pressure admitted into the space between the discs causes them to bulge outwards. Two curved levers pressing against the discs, communicate motion to the index by means of a rack and pinion, the bulging of both discs being utilised.

The action resembles that of the aneroid barometer, which is stated to have been first constructed by Vidi in 1847.

491. Steam and water gauge. Contributed by Messrs. Chadburn Bros., 1862. M.836.

In this gauge, patented by Mr. A. Chadburn in 1856, the pressure to be determined is measured by the amount of bulging it causes in a flexible disc of sheet metal secured round its edge to a circular box, into which the pressure is admitted. The slight movement obtained is multiplied by levers that transmit it to the index.

492. Pressure gauge. Contributed by Messrs. J. Dewrance and Co., 1862. M.366.

This form of pressure gauge was introduced in 1849 by Mons. E. Bourdon, who discovered the action upon which it relies when attempting to remove indentations from a coiled pipe by the application of internal pressure. He noticed that as the pressure was increased the pipe slightly straightened, and by fitting the fore end with a pointer, found that reliable readings were thus obtained.

As now constructed, the gauge consists of a closed curved tube of elliptical section, with one end fixed and the other connected by multiplying gear with the index. Pressure admitted to the interior of the tube, through the fixed end, tends to change the elliptical into a circular section, and thereby straightens the tube.

493. Bourdon gauge tubes. Lent by Messrs. Schäffer and Budenberg, 1894. M.2564.

These specimens illustrate the method of manufacture of two types of Bourdon tube; one is the ordinary tube for steam gauges, and the other the tube of the hydraulic gauges for excessively high pressure. For the steam gauge the tube is made from sheet metal with a brazed joint along what will be the inside of the coil. When making the joint the tube is somewhat circular, but is afterwards flattened to an elliptical section of about ·625 in. by ·187 in., which is then bent to the coil form. The hydraulic gauge is made from a short length of octagonal steel bar, bored up the centre, afterwards screwed at the ends, and greatly reduced externally so as to obtain sufficiently thin walls, while retaining the strength at the screwed extremities. The tube is then heated and bent to the form shown.

494. Recording pressure gauge. Contributed by the Seal Lock and Registering Pressure Gauge Co., 1874. M.1334.

The peculiarity of this gauge, patented by Mr. Everett in 1873, is that, in addition to the ordinary indication of the actual pressure, it is

made to register the number of times a given pressure has been exceeded in the working of the boiler to which the gauge is fixed, and also the extent to which such pressure has been exceeded. The latter object is effected by a short index or pointer, which turns about the same axis as the ordinary index, and is pushed forward by it as the pressure rises, and remains as a record of the maximum attained. The number of times that a given pressure has been exceeded is recorded by three small pointers working on one axis, driven by a system of ratchet-wheels.

495. Vacuum gauges. Lent by Messrs. Schäffer and Budenberg, 1888. M.1900 and M.1905.

These are for showing the degree of vacuum existing in the condenser of a steam engine. One has a thin disc, which, under the pressure of the atmosphere, is bulged inwards to an extent determined by the unbalanced pressure resulting from the interior of its supporting box being in connection with the condenser. The movement is multiplied by a sector gearing into a small pinion on the index spindle, and the scale is so graduated that the reading gives the reduction of pressure in inches of mercury.

In the other a Bourdon tube is used and arranged for reading the pressure in the condenser, or the boiler pressure, provided it does not exceed 30 lbs. above atmosphere.

496. Steam pressure gauges. Lent by Messrs. Schäffer and Budenberg, 1888. M.1902-4.

Two of these gauges are for steam pressures up to 300 lbs. per sq. in. The red line and figures on the dial are to indicate to the stoker the maximum pressure at which the boiler is to be worked. The curved tube of flattened or elliptical cross section, of the Bourdon type, is of steel, and is partly visible through the hole in the dial.

In the third example the dial graduations are in atmospheres as well as pounds per sq. in., steam pressure being generally expressed in atmospheres on the Continent.

497. Hydraulic pressure gauge. Lent by Messrs. Schäffer and Budenberg, 1888. M.1901.

This gauge is adapted for the high pressures employed in hydraulic machinery. The scale on the dial corresponds to tons per sq. in.; there is a second index to record the maximum pressure attained.

498. Pressure gauge. Lent by Messrs. G. Salter and Co., 1887. M.1852

This modification of the Bourdon gauge was patented by Mr. G. Salter in 1879. The free end of the flattened pressure tube is provided with a pin, which fits in a radial slot very near to the centre of the index, so that the slight movement of this pin is directly magnified by the long index arm.

Measurement of Properties of Materials.

499. Cement testing machine. Lent by A. H. Kuhlmann, Esq., 1892. M.2468.

This machine is for testing the strength of cement by determining the breaking resistance of a briquette prepared from it in a special mould. A cast-iron standard carries two levers; the upper one has a leverage of 10 : 1, and is connected by knife edges with the lower lever, whose ratio is 5 : 1. The test piece is held by clips, designed to secure an axial pull, and the power is gradually applied by permitting shot to run from a cistern into a cup hanging from the extremity of the upper lever. The necessary counterbalance weights and adjustings are fitted, and there is a lever below the shot can which cuts off the feed of shot as soon as the cup descends owing to the specimen breaking. A vertical spring balance is provided, upon which the shot cup can be weighed, and the breaking load be read. The machine exerts a maximum pull of 1,000 lbs., and the combined leverage is 50 : 1.

500. Thurston's oil tester. Lent by Messrs. W. H. Bailey and Co., 1894. M.2572.

This is an example of the smaller class of oil tester invented by Prof. R. H. Thurston. The test spindle is carried in bearings and driven by a small pulley. The overhanging end of the spindle is formed into a journal which carries, by means of brasses, a pendulum; a screw and spring arrangement regulate the pressure upon the journal. The large figures on the face of the pendulum give the total pressure, and the small figures that on the bearing surface in lbs. per sq. inch. As the journal rotates it tends to carry the pendulum round with it, and the pendulum inclines until its moment, with respect to the axis, balances that of the friction between journal and bearing. The figures on the graduated arc are such that, if divided by the total pressure on the bearing, the co-efficient of friction with the oil under test is obtained.

To determine the durability of the oil it is fed in by means of a chemist's "dropper"; a certain number of drops are supplied to the bearing, and the journal is rotated until the thermometer fitted in the pendulum indicates a certain rise in temperature. The number of revolutions is recorded by the counter attached, and when compared with the results from a standard oil shows the relative durability of the sample.

The liability of the oil to "gum" is found by allowing the bearing to stand wetted with the lubricant for a certain period—12 or 24 hours. Then the journal is rotated, and the co-efficient of friction found as above, the minimum co-efficient being taken and compared with that of the standard oil. In the first and last experiments no attempt is made to measure the quantity of oil supplied to the bearing.

Measurement of Temperature.

501. Hot blast pyrometer. Received 1897. M.2975.

This instrument was patented by Mr. H. Hobson in 1873, as a means for determining the temperature of the heated air supplied by a hot-

blast stove to a blast furnace, and has been extensively used. As this air is frequently at a temperature of over 700 deg. C., a mercurial thermometer placed in it would be destroyed, but by this apparatus the hot air sampled is mixed with a large amount of cold air that so reduces the temperature as to bring it within the range of an ordinary thermometer, from the reading of which the higher temperature is deduced.

The instrument consists of a metal plug fitted with a wooden handle and two branches. The plug is hollow and is pressed into an orifice in the blast main, and the hot blast passing through the plug is delivered as a jet within one of the branches. This jet, by its inductive action, draws in external air from the other branch, while by a contained thermometer the temperature of the combined escaping jet is indicated.

502. Electrical pyrometer. Presented by Messrs. Siemens Bros. and Co., 1885. M.1750.

This is a pyrometer for measuring the temperature of furnaces by means of the varying electrical resistance of platinum at different temperatures. It consists of an insulated coil of fine platinum wire, wound upon a core of fire-brick, enclosed within a sheath of iron pipe; the end of the iron sheath is in this case replaced by a glass tube to show the internal construction. Conducting wires from each end of the coil are carried through the back end of the sheath, and connected with the poles of a battery. The front end is thrust into the furnace, and allowed to remain until the heat has penetrated to the platinum coil; the strength of the electric current in the circuit varies according to the temperature to which the coil is subjected.

In the example shown the heated-coil is joined in parallel with a resistance kept at a constant temperature, and a voltameter is placed in each circuit. By noting the volumes of gases evolved and referring to tables, the temperature of the heated coil is obtained.

Measurement of Work.

503. Watt's steam engine indicator. Lent by E. A. Cowper, Esq., 1890. Plate IX., No. 6. M.2299.

This instrument was introduced by Watt, but the period of its invention is uncertain from his having kept it secret, owing to the very great assistance he found it afforded him in adjusting the valves of a steam engine. In 1796 he published a description of a pressure gauge consisting of a small spring loaded piston for connection with the steam cylinder of an engine, but in this form it was only a modification of his vacuum gauge (*see* No. 485). The important addition to the above of a pencil on the piston-rod, arranged for marking on a sheet of paper moved by the engine, is believed to be due to John Southern, one of Watt's staff. As thus improved, the instrument became a recorder of the pressure existing in the cylinder at every point of the stroke, and gave a diagram from which the work done during the stroke was easily determined. In Watt's patent of 1782 there is a diagram of the pressures throughout the stroke of an engine working expansively, but this is clearly the result of calculation, and it is not probable that the indicator had at that time been invented.

The instrument shown formerly belonged to one of Boulton, Watt and Co.'s agents in Manchester, while the diagram was taken in 1840 by Prof. E. Cowper.

The indicator has a vertical brass cylinder 1·13 in. diam. (one sq. in. area) fitted with a piston, the upper extremity of the rod of which is provided with a pencil. The piston is connected with the top of the indicator cylinder by a helical spring, so that any variation in the pressure below the piston will lengthen or shorten this spring, and thus cause the height of the piston to be a measure of the pressure below it. The lower end of the indicator cylinder is placed in communication with one end of the engine cylinder, so as to measure the varying pressure during the stroke. The motion of the paper was usually obtained from a point in the bridle rod of the parallel motion, the return movement being given either by string connected with a helical spring or by hand.

Owing to the low steam pressure employed by Watt, the connection between the indicator and the cylinder was made throughout by taper sockets and plugs, several of which are shown. On the older Watt engines the cylinder lubricators are also fitted in this way, screwing being adopted later when higher pressures were used.

504. McNaught indicator. Lent by Messrs. Bryan Donkin and Co., 1888. Plate IX., No. 7. M.1967.

This is a small example of the improved form of Watt's indicator, believed to have been introduced by Mr. John McNaught about 1825–30, in which, by the substitution of a drum for carrying the paper in place of the flat board, several serious practical difficulties were avoided.

The specimen, which, on account of its compactness, is probably not one of the earliest shown, has a drum 1·5 in. diam., and would give a diagram about 4 in. long by 3 in. high. The drum is removable, but is without clips, the paper having to be secured in position by cement. The piston is ·25 sq. in. area, and is directly connected with the pencil, the scale of pressure being 10 lbs. for 1 in.

505. McNaught indicators. Received 1897. M.2976.

These three examples of early indicators were made by Messrs. Chadburn Bros., and differ somewhat from No. 504.

The largest one has a cylinder ·5 sq. in. area with a travel of 4 in., while the drum is 2·2 in. diam., so that a diagram about 4 in. by 6 in. could be obtained. It has a combined pin and clip attachment for the metallic paper, and the marking point is connected wi h the piston by an arm having an adjustable spring-hinge, to give uni orm pressure. The scale of the spring is 1 in. for 10 lbs., but the piston-rod is extended upward, so that additional pressure can be applied by means of another spring contained in a removable cap when higher pressures are being used, the scale of the combined resistance being 30 lbs. to 1 in. There is in the box an independent bracket with a guide pulley, in addition to the pulley on the instrument; the weight complete with case is 12·5 lbs.

The smallest specimen has a cylinder of ·25 sq. in. area with a stroke of 2·5 in., while its drum, which is 1·5 in. diam., is fitted with the now usual spring clip for securing the paper. A diagram about 2·5 in. by

6 in. could be obtained, and the spring has a scale of 10 lbs. to 1 in., but there is an additional spring in a cap for use on high pressure engines.

The other example has a drum 1·9 in. diam. for the paper, arranged outside and concentric with the cylinder. The piston has a travel of 3 in., and the diagram would be about 3 in. by 5 in. The piston-rod has a crosshead passing through a guide slot and provided with a spring-hinged arm carrying the marking point and reaching downwards to the drum.

506. Locomotive indicator. Lent by the Great Western Railway Co., 1889. M.2269.

This is a steam engine indicator, designed by Sir Daniel Gooch, for taking diagrams from locomotives running at high speeds. The diagrams are drawn on a continuous roll of paper, instead of on detached sheets as in the ordinary form of indicators. The paper is pulled through by a pair of rollers driven by a belt from an axle of a locomotive or from the crank-shaft of an engine. The paper is kept back by a weight and cord, which tends to resist the unwinding of the paper from the reel; a similar arrangement of weight and cord causes the winding up, upon another reel, of the used paper. The cylinder is horizontal, and the piston-rod is attached to the short end of a lever which on its long end carries the pencil. A pair of bowed steel springs press on the end of the piston-rod. An example of the diagram obtained is shown.

507. Richards steam engine indicator. Lent by Messrs. Elliott Bros., 1888. Plate X., No. 1. M.1887.

This well-known form of indicator was introduced by Prof. C. B. Richards in 1862, and, except for high-speed engines, is still in general use. The great improvement it contained was the employment of a multiplying arrangement by which the stroke of the indicator piston is reduced, and the great distortion of the diagram, through the inertia of the moving parts of the instrument, is generally avoided. The capacity and convenience of the apparatus was also improved in other respects, and all the instruments since introduced have followed the methods that Richards invented.

The instrument consists of a small cylinder containing a piston held by a spiral spring. A drum is also provided to carry the paper on which the diagram is to be drawn, as in McNaught's instrument, but the paper arm is some little distance from the cylinder. Round the cylinder is fitted a collar with two projecting arms which support the two fixed points of a Watt parallel motion. The parallel point of this motion carries the pencil, and the piston is connected with one of the bridle rods at the point that has only one-fourth of the motion of the pencil. Owing to this arrangement, the pencil can be swung round to be in contact with the paper just when desired while the instrument is in action; a feature also of the greatest practical importance.

The example is fitted with Mr. Darke's detent, which is simply a pawl which can at will be allowed to engage in the teeth of a ratchet wheel formed on the drum, and so stop its rotation by preventing its return under the action of the drum spring as the cord slackens.

508. Kenyon's pistonless indicator. Lent by Messrs. Isaac Storey and Sons, 1890. M.2292.

In this steam engine indicator, patented in 1878 by Mr. J.W. Kenyon, a Bourdon tube takes the place of piston and spring. The motion, under varying pressure, of the free end of the tube is multiplied by a lever in the ratio of about 5 : 1, and the pencil is constrained to move in a straight line by Watt's parallel motion applied as in Richards's indicator. The connection between the tube and the parallel motion is by a rod with ball joints which enables the pencil to be drawn back from the paper on the drum when required. The drum is fitted with a stop motion, consisting of a small lever by which it can be raised sufficiently to disengage a short driving peg attached to the cord pulley.

509. Darke's indicator. Lent by Messrs. Elliott Bros., 1888. M.1888.

This arrangement of high-speed indicator was patented by Mr. E. T. Darke, in 1879. To minimise the inertia of the indicator piston, its rod is made hollow, while its motion is multiplied four times by a simple lever; the piston-rod carries a sleeve, which slides on this lever, and the pencil-holder slides similarly, but is guided in a vertical slot instead of by linkwork.

The paper drum has an external clamping bar by which the paper is held; the paper is in a continuous roll within the drum, and enough for a single card is exposed externally and secured. The instrument is also fitted with the detent patented by Mr. Darke in 1875, by which the rotation of the cylinder is easily stopped without interfering with the driving cord.

510. Crosby's indicator. Lent by the Crosby Steam Gage and Valve Co., 1896. Plate X., No. 2. M.1943.

This indicator, patented by Mr. G. H. Crosby, of Massachusetts, U.S.A., in 1879–82, is specially designed for taking diagrams from quick revolution engines. For this reason the size and weight of the moving parts have been reduced and their travels shortened, so as to minimise the disturbances due to momentum.

The piston is ·5 sq. in. area, and its travel is multiplied six times by the levers connecting it with the pencil, but the linkage possesses only slight inertia. To reduce the piston friction the loading springs are double with a ball connection to the piston to insure central pressure. Round the cylinder is an annular chamber open to steam, and serving as a steam jacket. The return movement of the drum is performed by a strong spiral spring of limited range, the intention being to moderate the fluctuation in the string tension due to the inertia of the drum.

511. McInnes Dobbie indicator. Lent by Messrs. Dobbie, McInnes, Ltd., 1905. M.3396.

In this steam engine indicator, which is an improved form of one patented by Mr. T. S. McInnes in 1887–8, a non-conducting vulcanite sheathing on the cylinder and other parts allows the operator to manipulate the instrument when hot and to change the spring without discomfort. The helical pressure spring is placed outside the cylinder

which is open at the bottom to facilitate cleaning. The piston is of case-hardened steel, recessed; it is ·5 sq. in. area and its motion is magnified six times by the pencil mechanism. The cord pulley frame can be set to give the cord a lead in any direction, and the length of the drum cord can be adjusted by means of a spring clip.

The example shown is a large size instrument for speeds up to 250 revs. per min.; smaller indicators of the same type are made for speeds up to 800 revs. per min.

512. The Tabor indicator. Lent by Messrs. John Musgrave and Sons, 1890. M.2307.

In this instrument the parallel motion is obtained by causing a small roller attached to the pencil arm to travel in a suitably curved guide fixed on the indicator cylinder cover. The piston-rod is attached to the piston by a ball and socket device, to prevent any tendency to bind, and with the same object the springs are double threaded. The paper drum is fitted with a detent stop motion, and a neat universal guide pulley gives a true lead to the cord from any direction.

513. Wayne's indicator. Made by Messrs. Elliott Bros. Received 1902. M.3258.

In this modification of the steam engine indicator, patented by Mr. M. J. Wayne in 1893, a semi-rotary piston is employed to actuate the pencil arm without the intervention of any linkwork.

The piston consists of a diametral plate, capable of working steam-tight within a cylindrical chamber having two fixed abutments, on opposite sides of which are inlet and outlet ports, as shown in the attached diagram. The indicator spring is of the double helical type, but works in torsion, and resists or measures the action of the steam by checking the rotation of the piston. The outer end of this spring is secured in a groove on the axle of the piston, while the inner end terminates in a brass plate having two holes fitting upon steel pins which project from the cylinder cover and allow the spring to shorten as the torsion is increased. To the opposite end of the piston axle the arm carrying the pencil is secured, and to allow for the circular path it describes, the diagram paper is held as a cylindrical surface by circular clips concentric with the piston axis and attached to an aluminium sliding frame. A string secured to one end of this frame imparts the reduced motion from the engine piston, and the return motion is obtained by a spring barrel. In the example shown, instead of the usual pencil, a hard steel tracing point is employed marking on black-faced paper.

To enable this instrument to obtain a diagram from an engine of exceptionally high speed, without the usual distortion due to the inertia of the moving parts, it is provided with an apparatus (shown detached) for taking the diagram in such cases in layers or "lines." This attachment, which can be secured to a horn projecting from the cylinder, consists of a segment of a worm wheel with a screw operated by a winch handle, and a steel tongue passing through a slightly elongated hole in the piston axle. By these means the rotation of the piston is limited to the amount resulting from the back lash in this hole, so that the pencil moves only through a small portion of this ordinary angular travel; but, by turning the worm wheel slowly throughout its range,

the series of layers are placed together in a way that gives a complete average diagram free from vibration disturbances, as shown in an attached print.

514. "Simplex" indicator. Lent by Messrs. Elliott Bros., 1905. M.3383.

In this steam engine indicator, which is a modified form of one patented by Mr. M. J. Wayne in 1894, the ordinary helical spring is replaced by a bow spring situated outside the cylinder away from the action of the steam. This can be easily removed and replaced, as its ends simply fit into grooves provided in the top of the extended piston rod and a fixed piece above it, and are retained in position by a small spring pin in one of the grooves engaging with a notch. The piston is ·5 sq. in. area, and its travel is magnified four times by the pencil mechanism which consists of a pantograph combination of levers.

A detent stop motion is fitted to the paper drum, and the tension of the drum spring can be adjusted by means of a milled head attached to its lower end.

515. Coffin's averaging instrument. Lent by Messrs. John Musgrave and Sons, 1890. M.2308.

This is a special form of planimeter arranged for measuring indicator diagrams. Starting from a point in the toe of the diagram, and with the measuring wheel at zero, the tracing point is led round the diagram when, on completing the circuit, the fresh reading on the wheel is the area of the diagram in square inches. By now sliding the tracing point vertically up the diagram, until the measuring wheel again reads zero, a height is obtained equivalent to the mean ordinate, and when measured with the indicator scale, gives the average mean pressure throughout the stroke.

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516. Transmission dynamometer. Made by Messrs. Siemens Bros. and Co. Received 1887. M.1877.

This apparatus for measuring the power transmitted by a belt connecting one pulley with another, is an improved form of the dynamometer brought out by Von Hefner Alteneck in 1872. A somewhat similar arrangement had been proposed by George Davis as early as 1843.

The amount of power that is being conveyed at any instant is determined from the difference in the tension of the tight and slack sides of the belt, and this is measured by an adjustable spring balance, which brings a swinging pulley back into its normal position while it is being oppositely acted upon by the two sides of the belt. The apparatus is arranged in a rectangular frame, which is supported at a suitable height by a rigid column ; at the corners of the frame are guide pulleys, by which the two sides of the driving belt are brought near together and parallel, but these parallel portions are forced apart again, in the middle, by a single pulley carried on a swinging lever provided with a counterbalance weight and a spring balance. When in use, the spring balance is adjusted by hand till the swinging lever is brought to the

normal position; an oil "dash-pot," is added to damp out vibrations, and two intermediate guide pulleys keep the two angles of the belt equal.

517. Transmission dynamometer. Made by R. Shepherd, Esq., 1892. M.2660.

This form of dynamometer coupling was introduced about 1882 by Profs. W. E. Ayrton and J. Perry. The adjacent ends of the transmitting and receiving shafts are coupled by tangential helical springs, the extension of which indicates the torque transmitted. The reading is obtained upon a fixed scale, by means of a bright bead revolving with the coupling and moved radially by the extension of the springs, so that the diameter of the circle it describes varies with the torque.

ELECTRICAL MEASUREMENTS.

518. Ammeter. Made by Messrs. Siemens Bros. and Co. Received 1902. M.3224.

This instrument—an improved form of one described in 1846 by W. Weber, as an application of Ampère's experimental apparatus of 1820—measures the strength of either a continuous or alternating current by the attraction exerted between a fixed and a moveable conductor through which the current is passing, without the intervention of any steel or other magnets. The measurement is effected by determining the amount of torsion required from a spring, to neutralise the deflection produced by the action of the currents; on account of this direct measurement of the forces exerted the instrument is generally known as an electro-dynamometer.

The example shown is for measuring currents up to 200 or 500 ampères according to the terminals used. For the larger currents the path is from the left-hand terminal upward through one leg of a stout ∩ of copper and down to the other extremity, which contains a circular bath of mercury; from this bath the current proceeds up one leg of a similar ∩ shaped piece of copper, suspended by silk thread, and down the other into a lower mercury bath connected with the central terminal. The front of the suspended ∩ carries a vertical finger and its centre is attached to the lower end of a vertical helical spring, the upper end of which is connected with an adjustable finger above a horizontal dial. When a current passes through this system, the suspended copper ∩ carries its finger to the right, but, by the centre head, torsion can then be applied to the spring until the finger is returned to its normal position. From the amount of torsion thus required the strength of the current is obtained upon reference to a table supplied with the instrument, the torsion increasing as the square of the current and the constant being determined by experiment.

For weaker currents the right hand and central terminals are used, the entering current, instead of going through the big fixed copper loop, traversing a fixed vertical flat coil of insulated copper tape and then through the suspended copper ∩ as before, the solenoid owing to the greater number of turns increasing the action on the suspended conductor.

At the side of the main standard is a screw by which the heavy

suspended conductor can be lifted and firmly secured when the instrument is to be moved, while at the top of the dial is a light screw for adjusting the suspension filament.

519. Ammeter and voltmeter. Lent by the Electrical Power Storage Co., 1885. M.2213–4.

These instruments measure the quantity or the pressure of the electricity passing by the intensity of the magnetism generated by a coil, the measurement being performed on a steelyard. The shorter arm of the steelyard consists of an iron rod arranged over one pole of an electro-magnet, and the longer arm of the lever is fitted with a sliding weight, and graduated to indicate the current or the voltage, the examples reading up to 20 ampères, or 50 volts. To use an instrument, the weight is placed at the extremity of the lever, and gradually moved towards the fulcrum until its action is so diminished that the passing current can overcome it and pull down the iron portion. The terminals are brought near together and fitted with a plug, so that the coil can be thrown out of the circuit when required. A small compass needle is let into the top of the ammeter, and provided with an ivory indicator, which shows the direction of the current.

In the ammeter the whole of the current used passes through the magnet coil, but in the voltmeter the current used is that through a shunt circuit of high resistance, and this circuit is only completed when a reading is being taken.

520. Ammeters and a voltmeter. Presented by Messrs. Crompton and Co., 1899. M.3051–3.

These three instruments embody a construction patented by Messrs. R. E. Crompton and G. Kapp in 1883, in which the strength of a current is measured by its action on a needle, but independently of the magnetism of the needle. The current traverses two coils of unequal turns, acting in opposite directions upon the needle; the smaller coil has an iron core piece by which its lines are so collected that its action exceeds that of the larger coil. As the current increases, however, the iron core approaches saturation, and so ceases further to benefit its coil; the larger coil therefore gains in its relative action, and the deflection of the needle advances.

In (*a*), which is an ammeter reading up to 150 ampères, there are four vertical coils of wide insulated copper tape; these are arranged in pairs, which are of unequal winding, and the smaller one of each pair has an iron core. At the centre of the instrument is a spindle carrying an astatic pair of needles and a long indicating finger of aluminium. At first, the small cored coils hold the finger near zero, but with heavier currents they are overpowered by the larger open coils.

In (*b*) nearly the same arrangement is adapted for use as a voltmeter. There are two small vertical coils with iron cores and two larger coils without cores, while in the centre of the instrument is an aluminium index containing two small magnets. The coils are wound with wire of high resistance, and further resistance is obtained by an external winding of fine wire, so that a total resistance is obtained that limits the current transmitted to a very small amount. The deflection of the index needle measures the voltage. There is a small switch at the base of the instrument by which the indicating current may be reversed or its circuit broken.

In (*c*), which is another ammeter, the arrangement is somewhat different. The current first passes through two C-shaped coils containing small iron cores, which act upon a small central magnetic needle, and tend to maintain it at the zero mark. The current then passes through a copper bar immediately beneath the needle, thus exerting a deflecting action. For small currents the coils almost overpower the magnetic action of the simple current, but as the current is increased and the cores approach saturation the direct action of the simple current becomes relatively more pronounced, the deflections of the needle accordingly increasing. There is a sliding bar, by which the instrument can be short circuited when readings are not required.

521. Ammeter and voltmeter. Received 1902. M.3242.

In these simple instruments, which were patented in 1890 by Messrs. E. Hartmann and W. Braun, the measurements are derived from the extent to which a vertical core, suspended by a spring, is pulled downward by a coil through which a current is passing. The coil surrounds the lower part of the core which, to insure greater uniformity in the graduations, is made tubular and has two pear-shaped holes cut in its side, so as to reduce the iron section near its lower extremity. A pointer connected with the core gives the reading on a vertical scale, which encloses the helical spring.

522. Ammeter. Lent by C. A. Müller, Esq., 1890. M.2348.

This instrument, made by Messrs. Schückert and Co., has a moving soft-iron system controlled by gravity, but capable of some displacement by the magnetic action of the passing current.

A piece of soft sheet-iron, bent at its outer end, is mounted upon a horizontal axis eccentric to the curve of a massive copper loop, arranged vertically, through which the whole of the current to be measured passes. The current produces a magnetic field having its maximum intensity near the inner edge of the loop, so that the bent part of the soft iron is attracted towards it. Mounted on the same axis as the iron is the pointer, and also a short counterbalancing arm for adjustment. The pointer indicates on an experimentally graduated dial the magnitude of the current, the example shown reading from 100 to 500 ampères; for smaller currents the copper loop is replaced by a conducting helix.

523. Ammeter. Made by the General Electric Co. Received 1902. M.3216.

This instrument, patented in America in 1896 by Mr. W. Waddell, indicates by the attraction exerted by the current in a helical wire upon an entering wire core.

The conducting circuit is formed of stout copper wire, to minimise resistance, coiled into a few turns of an open helix which is then curved into an arc of a circle. Into this coil enters a concentric iron wire carried by a pivot at the centre of the arc, and provided with an index and an adjustable balance weight. When the current flows the iron wire is drawn into the coil against the action of gravity, and the extent of the movement shows, upon an experimentally graduated scale, the strength of the current up to a maximum of 200 ampères.

524. Cardew's voltmeter. Received 1886. M.3130.

This is a sectional example of the instrument patented by Major P. Cardew in 1883 for measuring differences of potential by the expansion, through heating, of a length of fine high-resistance wire connecting the terminals to be tested. The temperature of the wire rises until the heat radiated equals that generated.

The instrument consists of a combined iron and brass tube 3 ft. long, having a joint co-efficient of expansion equal to that of the measuring wire contained within it, which is of platinum silver, ·0025 in. diam. The wire is fixed at one end to a terminal of the instrument, and then passes to the other end of the protecting tube and round a return pulley mounted in jewelled bearings, back to a thread passing round the arbor of an index hand, and on to a tension spring. The circuit through the measuring wire is continued through an additional length of resistance wire and a length of fuse wire ·0014 in. diam., by which a total wire resistance of 343 ohms is obtained in the example shown, which is graduated for reading from 20 to 120 volts. This form of instrument is usually kept connected with the mains to be tested; it is suitable for alternating as well as continuous currents.

525. Voltmeter. Made by Messrs. Nalder Bros. and Co. Received 1901. M.3169.

The arrangement of this instrument, which, by the substitution of larger wire in the coil, would be converted into an ammeter, was patented in 1889 by Messrs. Nalder, Crowley, and Soames.

In it the measurement is performed by the movement of a light soft-iron bar, attached to a horizontal spindle turning in bearings and fitted with an aluminium finger and an adjustable balance weight. The spindle is arranged within a reel of insulated wire, whose ends are brought to terminals, by which connection can be made with the two leads whose difference of potential is to be determined. Within the reel, and close to the soft-iron bar, is a fixed piece of soft iron, which, when a current is flowing through the coil, is magnetised similarly to the bar attached to the spindle, the mutual repulsion moving the finger by overcoming the action of the balance weight; by placing the coil on one side of the centre of the instrument, a symmetrical arrangement on the dial is secured. To minimise the amount of energy absorbed by the apparatus, the coil is formed of fine insulated German silver wire, giving a total resistance of 2,400 ohms.

526. Watt-meter. Made by Messrs. Siemens Bros. and Co. Received 1902. M.3223.

This apparatus, for measuring the power absorbed by an electrical circuit, is of the electro-dynamic type and in construction closely resembles the ammeter No. 518. The current arrives by one of the large terminals, and, passing to a central mercury bath, enters one leg of a suspended ∩ of copper, and leaves by the other leg which dips into a mercury bath connected with the other terminal. This copper ∩ is suspended by a silk thread, and provided with a vertical helical spring connecting it with an adjustable head by which the torsion requisite to neutralise the deflection can be applied and measured. Fixed to the standards of the instrument is a vertical flat coil of insulated

copper wire, the ends of which are connected, through a safety fuse, with the two smaller terminals. From these terminals leads are taken to the extremities of the circuit under investigation, so that a current is sent through the coil proportional to the voltage involved, while the main current flows through the suspended conductor. The deflecting action upon the suspended copper ∩ is proportionate to the product of the currents involved, so that the torsion which has to be applied to balance it is a direct measure of the watts being exerted; the dial reading in this example requires to be multiplied by the constant 283·8 to give the numerical result in watts. As this instrument is not being continuously read, the circuit from the voltage coil is fitted with a spring key which breaks it when not in use.

527. Watt-hour meter. Lent by Killingworth W. Hedges, Esq., 1898. M.3029.

This meter was patented by Mr. St. G. Lane-Fox in 1878–81, and is for use on a continuous current system.

The motion for the recording apparatus is derived from the oscillations of a horizontal swinging arm, attracted alternately by two electro-magnets on a shunt circuit, and therefore varies with the voltage. This motion is transmitted to the counting mechanism by a ratchet gear turning a vertical conical roller, which, by friction, drives a disc directly connected with the recording indexes. The spindle of the disc is, however, lifted by a lever connected with the armature of an electro-magnet in series with the main circuit, so that the position of the lever is controlled by the current passing. The resulting motion shown on the index dials is therefore determined by the total current passed and its pressure.

528. Watt-hour meter (working). Lent by the General Electric Co., 1892. M.2460.

This meter, patented by Dr. H. Aron in 1884, is a development of Ayrton's ergmeter, which consisted of two clocks, in one of which the pendulum was a magnet which swung over a coil carrying the current to be measured. The accelerating action of the current caused this clock to gain, and the difference in the reading of the two clocks measured the quantity of electricity that had passed.

The Aron meter has two clocks in one frame, with their wheel trains connected by a bevel-wheel differential gear. The two bevel wheels run loose on a central shaft, and are connected by a bevel pinion which is loose on an arm projecting from this shaft. The two bevel wheels are driven in opposite directions by the two clocks, and any difference in their speeds will cause the arm carrying the connecting bevel pinion to revolve, and this motion, which is proportional to the energy passed, is registered by a counter. The left-hand pendulum is of the ordinary type, while that to the right is of the same effective length, but has its bob in the form of a fine wire coil, free to oscillate within a fixed coil of stout wire. The main current passes through the fixed coil, and a shunt current through the pendulum coil.

529. Watt-hour meter. Presented by the British Thomson-Houston Co., Ltd., per F. Holden, Esq., 1905. M.3412.

A meter of the discontinuous or intermittent integrating class, to which the example shown belongs, combines an ammeter or a watt-

meter with a clock which, at regular short intervals of time, advances the recording mechanism through amounts proportional to the ampères or the watts. The total motion of the mechanism is proportional to the ampère or watt hours, but such an instrument is not suitable for use on a circuit where the current is liable to vary greatly during a short period of time.

The instrument shown, patented by Mr. J. Cauderay in 1883–8, includes a watt-meter of the Siemens dynamometer type with a long horizontal pointer, the end of which moves above a horizontal lever hinged at one extremity. An electrically driven clock imparts an up and down motion once per minute to this lever, which raises the end of the pointer with it. The pointer in turn raises a hinged frame carrying a friction ratchet which drives the recording mechanism. The latter is thus moved every minute through an amount depending upon the distance of the end of the pointer from the lever's fulcrum, which distance is proportional to the watts, the zero position of the wattmeter pointer being above the fulcrum where it receives no vertical motion. The shunt coil of the wattmeter is mounted on a vertical spindle carrying two arms to which are attached, in an adjustable manner, two opposing spiral springs.

A flat spiral spring and an elongated armature, actuated by four coils which are excited by a shunt circuit, are attached to the vertical axis of the balance wheel of the clock. The arrangements for making and breaking this circuit are such that no impulses are given to the balance wheel when the amplitude of its vibrations exceeds a certain amount. The balance spindle communicates an oscillatory motion to a pawl driving a ratchet wheel, to the axle of which a swash plate is secured. The latter imparts the necessary up and down motion to the horizontal lever by means of a roller, which is mounted on the lower part of the lever and rests on the swash plate.

The example shown is for use on a continuous current circuit of 50 ampères at 100 volts.

530. Ampère-hour meter (working). Presented by the British Thomson-Houston Co., Ltd., per F. Holden, Esq., 1905. M.3411.

This discontinuous integrating meter was patented by Mr. M. J. R. Jacquemier in 1887–8, and includes an ammeter consisting of an iron armature mounted on a horizontal axis between the poles of an electro-magnet which is excited by the current to be measured. The armature carries a metal pointer, and its movements are controlled by a flat spiral spring.

The clockwork is driven by springs and consists of two distinct wheel trains. One of these, constituting a time clock, is controlled by a lever escapement, and effects, at intervals of five minutes, a series of operations whereby the second train, which gears directly with the counting mechanism, is allowed to move until a pin projecting from a swinging lever comes into contact with the ammeter needle.

This swinging lever is pivoted on a toothed sector which is connected with the recording train by non-circular wheels, so designed that the amount through which the counting mechanism moves on each occasion is proportional to the ampères passing.

Mounted on a wheel of the time clock which revolves once in five minutes, is a disc carrying a pin which effects the operations. It first engages with a bell-crank lever carrying a stop-pin, the raising of which

releases the recording train, which is then free to move until the pin on the swinging lever touches the ammeter pointer. When this occurs the upper end of the lever, which is placed between fixed stops and has a slot embracing a pin connected with a small arm, receives a slight lateral displacement which causes the small arm to stop the motion by locking the mechanism. The pin on the disc next engages with a second bell-crank lever which carries one pivot of a moveable wheel which connects the recording train with the toothed sector. This is thrown out of gear and a spiral spring then pulls the sector and the lever back to their initial positions, ready for a repetition of the operations.

The ammeter pointer is connected with the armature by a spring which prevents any shock, due to the armature moving with a variation of the current, being communicated to the mechanism. The example shown is for use with continuous currents up to 90 ampères.

531. Watt-hour meter. Presented by the British Thomson-Houston Co., Ltd., per F. Holden, Esq., 1905. M.3413.

This discontinuous integrating meter, patented by Mr. A. Frager in 1889–90, was at one time largely used by the Paris electrical supply companies.

Like the Cauderay meter, No. 529, it contains a watt dynamometer carrying a long horizontal pointer but has a more sensitive arrangement for recording the deflection. The pointer is mounted on the shunt coil of the watt-meter, which is suspended by a wire, and its end moves along a radius of a horizontal snail plate which is mounted on a frame pressed upward by a spring. This frame also carries a pawl which, when the snail is depressed, engages with a circular rack attached to the recording mechanism. The snail is rotated uniformly by an electrically driven clock and makes one revolution in five minutes. Once in each revolution the end of the pointer comes into contact with the snail and depresses it, causing the recording mechanism to be moved through an amount depending on the angle of contact. The snail is so shaped that this amount is proportional to the watts, the pointer end being nearest the centre of the snail when the watts are a maximum; the mechanism can therefore be made to record watt-hours.

The end of the pointer carries a small wedge and is raised on to the snail plate by a bevelled piece situated in front of the radial edge of the snail; while in contact with the snail the pointer is pressed upward against a bridge piece which locks it.

The balance wheel of the clock is fitted with a flat spiral spring and consists of a nearly complete circle with soft iron pieces on each side of the gap. When at rest these pieces are placed unsymmetrically with respect to a solenoid excited by a shunt circuit, for making and breaking which suitable arrangements are provided. An eccentric on the balance spindle carries a pawl engaging a ratchet wheel secured to the same axis as the snail plate, which thus receives its motion.

532. Watt-hour meter (working). Presented by the British Thomson-Houston Co., Ltd., per F. Holden, Esq., 1905. M.3414.

This meter, of the intermittent integrating class, is suitable for continuous or alternating current circuits, and was patented by Mr. J. A. Déjardin in 1892.

It combines a clock with a watt-meter consisting of a shunt coil, which is placed between two fixed series coils and is suspended from a point near the fulcrum of a horizontal balance beam. The three coils have a common vertical axis, and are so wound that the shunt coil is urged upward with a force proportional to the watts. On the same side of the fulcrum as the coil there is attached one end of a length of flat flexible chain, the other end of which is wound round a drum ; the opposite side of the beam carries a counterbalancing weight, which is so adjusted that when no current is passing the lever is in equilibrium.

The chain drum is so connected with the clock that the chain is gradually unwound from the drum every five minutes and at the end of each interval it is automatically wound on again. When a certain length of chain, proportional to the watts, has been unwound, its weight counterbalances the force upward exerted by the watt-meter coil and its end of the balance beam is depressed. The counting mechanism is connected with the clockwork by wheels mounted on the balance beam, which are thrown out of action when it is depressed. The mechanism consequently moves with the clock until the beam is depressed, the result being that it is moved through an amount every five minutes which is proportional to the watts, and it can be so designed that the index records watt-hours.

The connection of the clock with the chain barrel consists of a wheel which makes one revolution in five minutes and is mounted loosely on the barrel axle. This wheel carries an arm fitted with a spring catch, which drives the barrel by engaging with a pin projecting from an arm on the barrel axle. Once each revolution, when the chain has been unwound, an inclined piece on the spring catch engages with a fixed pin which pushes the spring catch back and disconnects the drum from the clock. A weight at the end of an arm, which is raised by the clockwork as the chain is unwound, then comes into action and rewinds the chain on the drum, an arrangement being provided to keep the balance beam depressed during this process.

The clockwork has two springs, both driving the same wheel train, which is controlled by a pendulum.

533. Watt-hour meter. Lent by the Aron Electricity Meter, Limited, 1904. M.3332.

This is an improved form of No. 528, from which it differs in being self-winding and self-starting ; it has also a device whereby errors due to differences in the natural periods of the two pendulums are eliminated ; this allows shorter pendulums to be used, thus rendering the instrument more portable and compact.

Both clocks are driven by one spring, a second differential bevel gear being introduced to allow of their moving at different speeds. The spring consists of a bent strip, one end of which is fixed while the other is secured to a Z-shaped iron rotor arranged between the poles of an electro-magnet ; whenever the spring runs down, the circuit through the electro-magnet is completed by a pin coming into contact with a plate, and the rotor then turns through about 75 deg., thereby winding up the spring.

The pendulums of both clocks carry shunt coils, and are influenced by the current passing through the series coils, over which they swing. The latter are so arranged that one pendulum is accelerated and the other retarded, thus giving greater sensitiveness. As in the earlier

example, the difference in speed of the two clock trains is proportional to the watts, and a differential gear communicates with a counting mechanism which records watt-hours in B.O.T. units. Errors due to lack of exact synchronism in the two pendulums are eliminated by an apparatus consisting of a commutator which every ten minutes reverses the direction of the current in the pendulum coils, so that the previously accelerated coil is retarded and the retarded one accelerated, while at the same time an extra wheel is thrown in or out of gear between the differential gear and the counting mechanism. The pendulum coils, being similarly wound, are astatic against any external magnetic influences.

The Aron meter is made for either direct or alternating currents; the example shown is of the switch-board type, and is intended for a direct current up to 15 amps. at 200 volts.

534. Series of experimental meters. Lent by Messrs. S. Z. de Ferranti, Ltd., 1895. M.2751.

These meters, devised by Mr. Ferranti, all register by recording the number of revolutions made by a small fan placed in a circular bath of mercury, the readings being given in ampère-hours. The whole current to be measured flows radially through a circular mercury bath, and also traverses a coil that generates a magnetic field, whose lines of force pass vertically through the mercury. The inter-action of the current and field causes the mercury to revolve, and this rotates the fan. All of these meters act in this way, but several modifications have been made in the method of construction, as represented in the following examples.

(a) In this meter, the current entering by an insulated terminal at the bottom of the case, is conducted to the centre of the mercury bath, through which it flows radially outwards to an enclosed ring connected with the upper end of an insulated copper helix, the lower extremity of which is carried out to the other terminal. The blades of the fan dip into the mercury, and the revolutions are recorded by the counter at the top.

(b) This meter has no iron in its construction, and can be used on an alternating supply; the current is led to the centre of the mercury bath and passes from the circumference through two copper coils of solenoid form, that give the vertical lines of force required. To prevent the irregularity that was found in the (a) construction resulting from the alteration of the surface of the mercury bath through centrifugal action, a vulcanite cover was inserted to prevent the heaping up at the circumference, and the fan is always completely immersed. To ensure starting with a small current, a shunt winding of fine wire is introduced in the magnetic circuit.

(c) This meter resembles (b), except that the magnetic field through the bath is greatly strengthened, owing to the good magnetic path provided by an upper and lower enclosing iron circuit. The finished meter is supported within a thin metal casing by insulating screws.

(d) Here the magnetic circuit is formed in a steel casting, within which the exciting coil is placed and enclosed; the fan is completely immersed in the mercury. The residual magnetism of the steel

greatly assists the fan in starting under small currents which alone would give but a very weak field.

(*e*) To prevent the heating that takes place in an ironclad magnetic circuit when excited by an alternating current, the magnet here is of the double horse-shoe type, laminated vertically. To protect the terminals, a terminal box is provided below, which can be opened without breaking the seal of the authorities who have tested the instrument.

535. Ampère-hour meter. Lent by Messrs. S. Z. de Ferranti, Ltd., 1895. M.2751.

This is a later form of the meter patented by Mr. S. Z. de Ferranti in 1883–7, and is shown with the pieces detached, so as to render the internal arrangements visible. The registration of the current is derived from the rotation taking place in a bath of mercury, when it is transmitting the current radially, and is at the same time traversed axially by magnetic lines of force.

The magnetic circuit is formed by a wrought-iron case closed at the lower end, and provided at the top with an iron cover; to the bottom of the case is attached a central pole piece of steel surrounded by an insulated copper helix. The current passes through the helix and induces a strong magnetic field between the top of the central pole piece and the cover, while the magnetism of the steel maintains a sufficient field for starting with a feeble current. The upper end of the helix terminates in an iron ring fitting on an insulating washer on the top of the pole piece. This washer has a central orifice, and within the ring is the bath of mercury which completes the electric circuit, by connecting the ring on the upper end of the coil with the pole piece. The mercury bath is closed by an upper insulating washer secured to a metal plug that projects upward through the cover, and forms the support for the counting train. This is driven by a worm cut on a vertical spindle passing through the plug and provided below with a small fan immersed in the mercury and partaking of its rotation. By the complete immersion of the fan, certain irregularities resulting from the rounding edge and changing surface of a rotating mercury bath are eliminated.

The meter is for use with currents up to 50 ampères, and is enclosed in an insulating protecting jacket, which is sealed after testing, the lower portion being removable to give access to the terminals.

This meter registers the ampère-hours independently of voltage.

536. Ampère-hour meter. Lent by the Westinghouse Electric Co., 1893. M.2530.

This meter, patented in 1888 by Mr. O. B. Shallenberger, is for use on systems in which the current is alternating, the registration being derived from the rotation of a small induction motor, the rotating part of which is a soft iron ring secured to a vertical spindle by means of a corrugated aluminium disc. The current is passed through a coil wound in two portions and enclosing a short-circuited coil consisting of sixteen copper loops. The axis of this short-circuited coil makes an angle of about 45 deg. with the main coil, and the currents in the main coil induce currents in the inner one which lag about 90 deg. in phase behind the primary current.

These two alternating currents of different phases produce a rotary magnetic field which causes the disc to rotate, under a torque that is proportional to the square of the ampères. The disc spindle, however, carries a four-bladed aluminium fan, the air resistance to which is proportional to the square of its speed of rotation, the result being that the speed of rotation of the motor is directly proportional to the ampères flowing. A pinion is accordingly fixed at the top of the spindle to drive a counting mechanism which records ampère-hours.

The instrument is calibrated by adjusting the angle between the copper loops and the main coils; there is, moreover, a pointer on one of the spindles of the counting mechanism which is always visible through a small window in the enclosing case, and by this the accuracy of the registration can at any time be checked.

537. Watt-hour meter. Lent by the Laing, Wharton, and Down Construction Syndicate, 1892. M.2465.

In this meter, patented by Mr. Elihu Thomson in 1890, the energy passed is recorded by an electro-motor, the speed of which varies with the watts transmitted. To render the meter suitable for alternating as well as continuous currents, no iron is employed in either the field or armature of the motor. The field consist of two coils of stout wire, one on each side of the armature. The armature is a hollow frame wound with a set of coils of fine wire on the Siemens drum principle, the commutator and brushes being of silver. The spindle is vertical and is carried with but slight friction on a jewelled foot-step. Near the foot of the shaft is attached a copper disc, which runs between the poles of three permanent magnets, the fields of which generate Foucault currents in the disc which forms a drag or load on the motor. By a worm on the spindle a counter is driven which gives the reading in watt-hours. A small plummet is contained in the instrument, by which it can be fixed level, and a tin case with a glass over the dial is fitted over the instrument for protection. The field coils are in series with the lamp circuit, and the armature coils, together with a non-inductive resistance, form a shunt from the lamp circuit, so that the armature current is proportional to the voltage. The torque of the motor is accordingly proportional to the ampères by the volts, *i.e.*, the watts, and the torque resistance of the copper disc is proportional to its speed, whence it follows that the speed varies as the watts. The current through the armature coils being shunted from the lamp circuit, there is always a slight constant field due to the flow of the armature current throught the field coils, and this is used to conteract the influence of pivot friction.

538. Ampère-hour meter. Made by Messrs. Chamberlain and Hookham. Received 1902. M.3214.

This is a continuous current meter of the motor type and was patented by Mr. G. Hookham in 1891–2. Its registrations are derived from the revolutions performed by a disc, through which the current is flowing radially while magnetic lines are passing through it in a direction parallel to its axis.

The permanent magnets employed to give the field are arranged vertically in a brass cylinder, and from their upper and lower ends extend two pole pieces which leave two gaps through which the lines of

force are passing vertically. The lower gap is filled with an insulated copper cylinder containing mercury, within which is a copper disc secured to a vertical axle turning on a pivot below and extending upward, where, in the upper gap, is an exposed copper disc; at the upper bearing this spindle is connected with counting mechanism for recording its revolutions. The current entering the instrument passes to the circumference of the mercury bath and flows through the mercury and the copper disc to an uninsulated portion at the centre of the cup, thus traversing the radial course which, in the magnetic field, causes the disc to revolve. This rotation is, however, impeded by the Foucault currents generated in the exposed disc, owing to the pole pieces in its vicinity having serrated faces which group the lines in sectors. The current passing through the instrument is, moreover, sent through two magnetic coils, for the purpose of correcting for the action of the flowing current upon the lines from the permanent magnet. The whole instrument is protected by a case secured by sealed nuts, but leaving sufficient space below for the insertion and attachment of the terminal leads.

539. Ampère-hour meter. Presented by the Electrical Co., 1903. M.3273.

This is a direct current meter which records through the rotation of a small magneto-electric motor driven by a shunted portion of the current. The armature consists of an aluminium cup wound with three coils of fine wire and revolving between the poles of a permanent magnet, while enclosing a stationary iron core. As this armature moves in a strong magnetic field the eddy currents produced in it exert the necessary retarding action without the assistance of a braking disc. As the driving force is proportional to the current passing and the braking resistance increases with the speed of rotation, the number of revolutions made by the armature is proportional to the product of the ampères by the time. This motion is communicated, by worm gear, to counting mechanism which records in B.O.T. units.

The instrument is calibrated by adjusting the resistance of the shunt wire, by means of a sliding clip which is finally soldered in position. A white line on the rotating cup is, however, visible through a small window in the protecting cover and, as the correct number of revolutions per minute per 1,000 watts is stated, the working of the meter can always be checked.

This type of ampère-hour meter is intended for small consumers, the one shown being designed for a maximum current of 5 ampères and a pressure of 110 volts.

540. Watt-hour meter. Presented by the Electrical Co., 1903. M.3275.

This is a direct current meter of the motor type, but in place of a rotating armature an oscillating coil is used, so as to avoid the frictional resistance of commutator brushes. The coil is included in a high resistance shunt circuit connecting the mains, whereby the current through it is proportional to the volts. It is mounted upon a vertical spindle which carries a contact arm moving between fixed stops, and the electrical connections are such that each time the arm engages with either of the stops the direction of the current in the coil is reversed. This causes the coil to be moved alternately in opposite directions by a series coil, which surrounds it and through which the main current passes.

The registering mechanism is actuated by a relay, consisting of two electro-magnets, and an armature which is made to reciprocate at the same rate as the moving coil; the necessary connections are such that when the coil reaches the end of an oscillation, one of the electro-magnetic coils is short-circuited and the armature attracted to the other, which causes the direction of the current in the moving coil to be reversed without the sparking due to a total breaking of the circuit. The reciprocations of the armature are communicated to the counting mechanism by means of a pawl engaging with a ratchet wheel.

The spindle of the moving coil carries an aluminium braking disc, moving between the poles of a permanent magnet, while a coil included in the shunt circuit is placed near the moving coil to compensate for friction and to enable the meter to start on small loads. In a modification of this meter the oscillating coil has two opposite windings which are alternately in circuit and short circuited.

The example shown is designed for currents up to 5 ampères, and a pressure of 220 volts.

541. Watt-hour meter. Presented by the Electrical Co., 1903. M.3274.

This is an alternating current meter patented in 1900 by the Allgemeine Elektricitäts Gesellschaft.

It consists of a small induction motor, the rotor of which is an aluminium disc revolving in a rotary magnetic field produced by two branches of the current differing in phase. There are series and shunt circuits, the series carrying the main current and the shunt connecting the pressure mains. Included in the shunt circuit is an inductive resistance or choking coil which produces a difference of phase of 45 degrees.

A laminated electro-magnet has three poles with a common keeper:—one leg is without coils, the central one carries the shunt coils together with a portion of the series, and the third is wound entirely with series coils. The rotating disc is placed between the poles and the keeper, and the interaction between the magnetic field, due to one of the circuits, and the eddy currents due to the other, which is of different phase, causes rotation of the disc. The torque increases with the watts, and, as the disc moves between the poles of a permanent magnet, a braking resistance, proportional to the velocity, is experienced, with the result that the speed of the disc is directly proportional to the power transmitted.

The revolutions of the disc are communicated to the counting mechanism, reading B.O.T. units, by means of a worm wheel and screw.

A small coil, without an iron core, is in parallel with the shunt coil, and when the main circuit is open causes a torque which just compensates for the friction and enables the meter to start on low loads. The meter is prevented from running idle by a piece of iron wire attached to the aluminium disc; the example shown is intended for use with currents up to 5 ampères at 230 volts.

542. Prepayment ampère-hour meter. Lent by the Schattner Electricity Meter Co., 1903. M.3266.

This is an electrolytic meter, patented in 1898 by Messrs. F. M. Long and E. Schattner, and is actuated by a shunted portion of the current.

It consists of a lever mounted on knife edges and carrying :—two buckets, the anode plate of a copper electrolytic bath, and two contact pins all on one side of its fulcrum, and a weight on the other. Initially the weight is just able to depress its end of the lever, consequently, when a coin is placed in the slot which guides it into one of the buckets, its end of the lever is depressed. This causes the circuit to be completed and allows current to flow until an amount of copper, proportional to the weight of the coin inserted, has been lost by the anode. The weight then again depresses its end of the lever and in the original form of the meter the circuit was broken. In the example shown, however, to avoid the house being suddenly left in darkness, the circuit is never broken by the meter, but instead a high resistance shunt circuit, generally in the form of a lamp, remains complete so that a feeble glow will continue from every lamp left on ; this reduced current passes through the cell, and its equivalent is, therefore, deducted from the supply given for the next coin inserted.

The electrolytic cell is shunted by a low resistance coil, so that only a small fraction of the total current passes through it. The cathode consists of a copper vessel which, together with the anode plate, is renewed after recording 700 units ; to prevent evaporation the copper sulphate solution has a layer of oil on its surface.

The meter is designed to take silver coins of the values 3d., 6d., and 1s., the weights of which are approximately proportional to their values. When the coins are removed by the collector he places equivalent standard weights in the second bucket; consequently the consumer does not ultimately suffer by the use of worn coins.

543. Ampère-hour meters. Presented by the Reason Manufacturing Co., 1903. M.3269–70.

These meters, patented by Mr. A. Wright in 1900, record the amount of electricity passed, by the amount of mercury electrolytically deposited by a shunted portion of the total current.

The electrolytic cell is arranged as a hermetically sealed glass chamber, with an annular trough at the top containing mercury, which forms the anode, while centrally within it is a conical ring of platinum foil which becomes the cathode ; the rest of the chamber is almost filled with a solution of mercurous nitrate which constitutes the electrolyte.

While current is passing, metallic mercury is deposited on the platinum cathode from which it falls into a vertical measuring tube beneath, the amount there collected representing on the scale the amount of electrical energy transmitted in B.O.T. units. The cell, however, together with a resistance coil of copper wire which is in series with it, is shunted by a low resistance, so that only about 1-200th of the current measured is passed through the cell.

The copper wire resistance is introduced to avoid irregularities through variations in temperature, for while the resistance of an electrolytic cell diminishes with increase of temperature, that of a copper wire increases, and the requisite constancy is obtained by the introduction of a suitable length of copper wire in the form of a resistance coil. The mercury in the annular trough is kept at a constant level by a bulb containing mercury and a solution of mercurous nitrate; the lower portion of the bulb communicates with the trough and the mercury is thus admitted as required by an action resembling that of a " bird-fountain."

The meters are protected by locked cast-iron casings provided with inspection windows. One of the two examples shown is designed for currents up to 5 ampères at 200 volts and reads to 250 units; the other reads up to 1,000 units and has enclosed with it a maximum demand indicator. (*See* No. 545.)

544. Prepayment ampère-hour meter. Lent by the Mordey Fricker Electricity Meter Co., Ltd., 1906. M.3437.

This electrolytic meter was patented by Messrs. W. M. Mordey and G. C. Fricker in 1904. It consists of a depositing cell having a fixed copper plate for its cathode, while its anode takes the form of a roll of thin copper strip of which a definite length is fed into the electrolyte by the operation of each coin inserted in the payment slot. The whole of the current to be measured is passed through the cell, and when a quantity of electricity corresponding in value to the coins inserted has been consumed, the copper strip is dissolved and the circuit is automatically broken at the surface of the electrolyte.

The operating coin drops into a pocket mounted on the same axis as a small handle placed outside the meter case, and a portion of the coin projects from the pocket into a groove in the end of a spindle. The latter is connected by toothed wheels with a roller, which feeds the copper strip into the cell and has sprocket teeth engaging with perforations in the strip. It is so arranged that half a revolution of the handle, when it is connected with the spindle by a coin, causes the strip to be fed through the amount corresponding to one coin. The motion of the handle is restricted by stops to half a revolution, at the end of which the pocket is inverted and the coin is free to fall into a box below. The electrolyte employed is copper nitrate, and the anode is prevented from approaching the cathode by two glass rods.

This meter is made to take pennies, eight of which can be prepaid. A counting mechanism records the total number of coins paid in, and the copper rolls are made to last for 600 pennies. The example shown is designed for currents up to 2 ampères at 200 volts.

545. Maximum demand indicator. Presented by the Reason Manufacturing Co., 1903. M.3270.

In selling electrical energy, a system introduced by Mr. A. Wright, of Brighton, is frequently employed, in which the maximum current used, as well as the total amount, determines the charge made. The price per unit varies according to a sliding scale, in which after a consumption representing that at the maximum rate for a certain period, generally one to two hours per day, has taken place, the charge for the remainder is reduced.

The maximum demand indicator shown, was patented by Mr. Wright in 1893, and can be employed for continuous and alternating currents. It consists of two glass bulbs connected by a U-tube containing a hygroscopic liquid. One of the bulbs is exposed, while the other is surrounded by a coiled strip of resisting metal carrying the current, so that the heat developed causes the air within this bulb to expand and drive the liquid into the other limb. From this it overflows into a small vertical tube, graduated to read the current then passing in ampères, so that the height of the fluid in this tube shows the greatest current that has been passed since the recorder was last set.

The instrument is reset to its zero reading by tilting it about its hinged supports till the liquid in the graduated tube flows back into the adjoining bulb. Owing to the action depending upon the heating of a volume of air, the instrument is sufficiently sluggish to ignore the heavy currents momentarily taken in starting a motor. The example shown records up to 5 ampères, and is enclosed within the same box as an electrolytic meter. (*See* No. 543).

546. Maximum demand indicator. Lent by the Schattner Electricity Meter Co., 1903. M.3267.

This instrument, for recording the maximum current passed, was patented in 1901 by Mr. L. B. Atkinson.

The current traverses a curved coil into which enters an iron wire core connected with a pivoted frame, so that the greater the current the further the core is drawn in. This core, however, carries a glass tube, the upper part of which is curved and contains a series of small metallic balls while the remainder contains oil.

When the core is drawn into the coil, the balls to the right of a vertical line passing through the pivot fall down the tube, the number thus falling depending upon the deflection caused by the current. A table on the frame shows the number of ampères corresponding to any number of fallen balls, also the number of units per quarter upon which the higher sliding-scale rate will be charged. The oil in the tube prevents the registration of a high current if it is of but brief duration. The example shown is intended for a demand not exceeding 10 ampères.

PUMPS.

In this section are included appliances for lifting and forcing liquids and gases against a head ; nearly all are motors reversed.

Baling Appliances.—This class includes nearly all the apparatus known to the ancient world ; they were originated in the remote past, and the greatest advance is traceable to the East, where, owing to the exigencies of the climate, the practice of irrigation was developed.

The simplest appliance is a gourd or other vessel lifted by hand ; an obvious addition to the vessel is a rope whereby water could be drawn from a greater depth. The pulley, windlass, capstan and tread-wheel were used as aids in winding the rope ; indeed, these mechanical powers may have been originated for performing this service. The work of lifting the vessel is saved by suspending it, either from a fixed point, as in the Dutch scoop and in the somewhat similar bail scoop, or from the longer arm of a counterbalanced lever, as in the " swoop " or " swape," which under different names has been most extensively used by all races in the past and continues in use, *e.g.*, the Egyptian shadoof, at the present day. To save human labour, the power of draught animals, flowing streams, or the wind is utilised in extensions of these ideas, arranged to repeat the operation automatically, such as the wheel with buckets on the rim, variously known as the noria, the Persian and the

Chinese wheel; the endless chain of pots; the Chinese pump (*see* No. 548) and its derivative the chain pump; rising and falling buckets; the reversed water-wheel or scoop-wheel, and the tympanum (*see* No. 547). Another appliance dating from the historical period is the water snail or Egyptian screw attributed to Archimedes, 240 B.C.

Pumps of this class are simple in construction, but their efficiency is low, their height of lift, with the exception of the windlass and bucket and of the chain pump type, is limited, and they can only deal with small quantities; they are consequently little used by Western nations.

Reciprocating Pumps.—The idea of a diaphragm or piston reciprocated within a closed box to exert pressure on a liquid would appear to have been first exemplified in the syringe. The provision of suitable valves to direct the streams resulted in the force pump, which appears to have been known more than 200 years B.C., as it is attributed to Ctesibius. Hero of Alexandria about 150 B.C. describes the manual fire-engine with two single-acting cylinders immersed in the water to be raised and provided with clack and poppet valves. The suction pump was in use about the same time, although the reason why water would not follow the piston to a greater height than about 25 ft. was not understood till the existence of atmospheric pressure was demonstrated in the 17th century. The height in excess of 25 ft. may be overcome either by having a solid piston when the pump is of the suction and force type, or by having a valve in the piston when direct lift is resorted to. The plunger or ram force pump in which the packing is transferred from the piston to the cylinders was known to the Romans; since reintroduced by Trevithick in 1797 for mine drainage, it has been the form used for the highest pressures, *e.g.*, hydraulic work. A closed collapsible connection between the piston and its fixed abutment gives the diaphragm pump or bellows. As indicating the extensive nature of pumping operations undertaken with simple means, the costly waterworks for supplying the needs of the palace of Versailles, completed in 1682 by Swalm Renkin or Rannequin, may be cited. Water was raised from the Seine at Marly in three lifts to an aqueduct at an elevation of 500 ft. The power was taken from the river by fourteen undershot water-wheels and was transmitted uphill by double lines of rods, to a maximum distance of 2,000 ft. At each lift were suction, force or lift pumps worked by rocking beams. The machine remained in use for over a century, although the efficiency was exceedingly low. Another important waterworks was that established at London Bridge in 1582 by Peter Morice and subsequently extended. In 1701 the plant was renewed and then consisted of four undershot water-wheels driven by the current or tide passing the arches of the bridge. Each was immersed mechanically to suit the state of the tide, and by gearing worked sixteen suction and force pumps, 7 in. diam. by 30 in. stroke, raising water through iron pipes to a height of 120 ft. The plant was used until 1822, when the new bridge was built.

The great need that existed for elevating large quantities of water for waterworks or mine drainage directed attention to new sources of power. Savery's engine for raising water by the direct pressure of steam (*see* No. 7) was applied in 1699 at York Buildings, in the Strand, but it was not till after Newcomen's atmospheric engine was brought out in 1712 (*see* No. 13) that any large development took place; for three-quarters of a century the steam engine was confined solely to the duty of working large pumps. In the hands of James Watt and his successors this led to high efficiency in the well-known Cornish engine (*see* No. 552).

The suction and force pump had been made double-acting at an early period by closing both ends of the barrel and duplicating the valves, so that by placing the barrel in line with a steam cylinder a simpler type than the beam engine is arrived at. If rotative parts are omitted the piston is free and can act on the water without shock. The difficulty of making the piston-rod control the movement of the valve was overcome in 1844 by H. R. Worthington, and the direct-acting type was introduced. The special case where the valve of one cylinder is controlled by the piston-rod of another placed by its side gives us the duplex type (*see* No. 559). In neither type can the steam be used expansively, but the difficulty has been overcome by compounding or by "compensators" so that this type can compete in economy with any other.

If water under a high head is available, its energy may be utilised so as to raise a smaller quantity to a higher head or *vice versâ*. Such water-pressure engines appear to have had their origin in Germany in 1748, and to have been introduced into this country in 1765; Trevithick adopted the construction in Cornwall in 1798 and other engines have since been built (*see* No. 567), but the type is more common on the Continent.

Owing to the elasticity of gases, changes in volume and temperature take place in compressing them. At the low pressures used for supplying air to furnaces (*see* Nos. 581–2) the rise in temperature is negligible, but at high pressures it becomes serious; in the compressors of Dubois and François, used for supplying the rock-excavating machines at the St. Gothard Tunnel in 1873, it was obviated by injecting cold water into the cylinder, hence known as a "wet" compressor. This had the advantage of filling the clearance space and ensuring complete discharge of the air, but it limited the speed of working to about 100 ft. per min. and made the air unnecessarily moist. In the "dry" compressor the cylinder is jacketed and cold water is circulated through it, about half the loss of work through heating being thereby avoided; clearance spaces must be reduced to a minimum and the only limit of speed is that at which the valves will operate satisfactorily. For compressing air to very high pressures it is now usual to work in stages, the pumps, of diminishing diameters, being usually on one long piston-rod, the air compressed in the first pump passing through external cooling pipes or "intercoolers" before being further compressed in the second pump, and so on; in this way the loss of

pówer through the thermal changes during compression can be greatly reduced, and several mechanical difficulties are avoided

Rotary Pumps.—These, although acting by force and suction, differ from the preceding class in the use of a rotating or oscillating "piston" to effect the enlarging and contracting of the pump chamber. Ramelli in 1588 describes one with an eccentric chamber and rotating blade (*see* No. 597), and also one in the form of two spur-wheels geared together in a closely-fitting casing (*see* No. 598). Rotary mechanism has been much more successful when applied to pumps than to motors, especially when restricted to moderate heads where the leakage due to the packing is small. The low speed of rotation that may be adopted is also an advantage.

Centrifugal Pumps.—These differ from the preceding classes in that the energy is used in giving momentum to the water instead of acting by positive pressure. In 1682 Denis Papin schemed the Hessian pump which had a wheel or impeller with four straight radial blades arranged in a circular casing. Several arrangements of Barker's mill reversed were proposed during the succeeding century, but nothing better appeared till 1818, when the Massachusetts pump was introduced; from this the rise of the present centrifugal pump may be said to date; this differed from Papin's mainly in being immersed in the water to be lifted, and in having an eccentric casing; it is thus less inefficient than the circular casing in converting the kinetic energy, that has been imparted to the water on leaving the impeller, into pressure energy. In 1839 Andrews brought out the efficient spiral or volute casing. In 1849 J. G. Appold determined by experiment the most efficient curve for the blades of the wheel (*see* No. 599). About 1850 Prof. J. Thomson first suggested the whirlpool chamber, a space surrounding the wheel in which a free vortex could be formed.

For high lifts the peripheral speed of the wheel must be high and the skin friction then becomes serious. Gwynne and others early tried to obviate this by employing two or more pumps in series, the several wheels being on the same shaft, but the efficiency proved low. Recently Sulzer and others have succeeded in obtaining efficiently any desired lift. A further advance in efficiency has been obtained by centrifugal pumps in which the passages are formed like those of an outward flow turbine reversed; these have also been arranged similarly in series for high lifts. Low first cost and upkeep and their capability of dealing with very large quantities of water in which solid matter may be suspended are the chief advantages of centrifugal pumps.

Where large volumes of air at a slight pressure are required for ventilation of mines and buildings the form known as a fan is almost exclusively employed (*see* No. 607).

Hydraulic Rams.—In these machines the temporary rise in pressure which results when the flow of water through a long pipe is suddenly arrested is employed to raise a small quantity to a considerable height. The first to make a practical application of the principle was John Whitehurst, who in 1772 took advantage of

the use that was made of a cock at the ground floor of the house, in order to raise water to a cistern on the upper floor. In 1796 Joseph Montgolfier independently invented the ram and made it self-acting by using, in place of the cock, a valve loaded so as to open when the water came to rest (*see* No. 609). Rams are now constructed which will lift water from a different source to that whence they obtain their power so that a dirty stream may be utilised (*see* No. 610). To raise water in quantity rams have been constructed with the momentum valve operated quietly by compressed air. Rams usually have a low efficiency, but require little attention and maintenance.

Baling Appliances.

547. Model of scoop wheel (working). (Scale 1 : 10.) Constructed by Mons. P. Regnard, 1899. M.3045.

This is a modern form of the "tympanum," which was an ancient water-raising appliance when described by Vitruvius, in the first century A.D. It consisted of a horizontal drum divided into four chambers by radial partitions, and partly immersed in the water that was to be raised; when the drum was rotated, water entered each chamber by an opening at the circumference, and afterwards escaped through another opening along the main axle. De la Faye, about 1730, replaced these chambers by pipes bent to an involute curve, thus greatly increasing the efficiency by reducing the useless circumferential velocity given to the water.

About 1830, Cavé brought the machine to the present form by fitting the drum with partitions curved to an Archimedean spiral, by the use of which the water is raised vertically through equal heights for equal angular movements of the wheel, so that the resistance is uniform. Cavé constructed several of these wheels 23 ft. diam., 3·28 ft. wide, which were immersed 4 ft. in the water to be raised. They were driven at a speed of 10 revs. per min. by spur gearing, as shown, and are stated to have raised 8,800 gals. of water per minute to a height of 3·28 ft. with an efficiency of 85 per cent.

As wheels of this kind can only raise water to the height of their axles, their use is restricted to low lifts; also, any temporary lowering of the head water in no way reduces the power required, and their effective speed is very limited. On the other hand, they have no inferior limit of speed, and can pump any kind of water without undue wear, while, under suitable conditions, their efficiency is high.

548. Models of Chinese pumps. (Scales 1 : 12 and 1 : 24.) Received 1862 and 1895. M.1670 and 2910.

These illustrate a form of pump frequently used for irrigation in China. There is a long inclined trough dipping into the lower water at one end and reaching above the higher level at the other; in the trough is the lower half of an endless chain provided with float boards just fitting it and returning over a spoked axle at each end. The upper axle in one model is provided with cranks driven by men working connecting-rods, and in the other by an ox turning a gin with wooden crown gearing.

Reciprocating Pumps.

549. Model of a Cornish pumping plant. (Scale 1 : 12.) M.2651

This complete detailed model shows the machinery erected in 1840 for draining the United Mines at Gwennap in Cornwall. The engine is similar to the larger model described in No. 552, but this example shows several additional details and modifications, as well as the engine and boiler-houses, and the arrangement of the mine-shaft.

The steam cylinder is 85 in. diam., with a stroke of 11 ft., and is jacketed with boiler steam. The engine valves are of the double-beat type, 15 in., 18·5 in., and 25 in. diam., worked by the usual tappet and weight gear, and controlled by a cataract. The condenser and air-pump are arranged on the outdoor side of the beam, and the condenser is surrounded by an open hot-well. The feed pump draws its water from the hot well, and delivers it through a coil placed in the passage through which the exhaust steam enters the condenser. The feed-water then passes through a heater of horizontal pipes, placed in the flue at the back of the boilers, from which it is fed as required. The beam is of cast iron in two parallel girders, with unequal arms, so that while the piston stroke is 11 ft., the pump stroke is only 10 ft.; the length of the beam is 34·2 ft., and its depth 7·12 ft. The main rod which works the pumps in the shaft is of timber balks, and has a section of 24 in. by 12 in. The excess weight of the rod above that necessary to force the water out of the pump barrels is corrected by five balance-bobs, two on the surface as shown, and three others in the shaft. These bobs consist of cast-iron beams counter-weighted by boxes containing stones. The large capstan and sheer-legs on the surface were constructed for use in erecting and repairing the pumps.

Steam is supplied by six boilers of the single flue or Cornish type, four 30 ft. long by 5 ft. diam., and two 34 ft. by 5·83 ft. diam., with flues 3·3 ft. diam. The six boilers deliver into a steam reservoir 30 in. diam. that runs the whole length of the boiler house.

The most economical results from this engine were obtained in 1842, when the mine was 1,207 ft. deep, and the load on the piston 12·05 lbs. per sq. in. The engine, making five double strokes per minute, exerted 114 H.P., The last return in 1851 showed a duty of 74 millions per 112 lbs. of coal consumed, while the load had increased to 15·8 lbs., and the H.P. to 165. The greatest working speed was 7·5 double strokes per minute in 1849, when the H.P. exerted was 220, and the duty 92 millions.

N.B.—This model is situated at the Eastern entrance to the Galleries.

550. Model of Cornish mine pumps. (Scale 1: 12.) Made by J. Arthur, Esq., 1843. M.2652.

This is a general representation of the complete arrangement of pumps employed in a deep mine and is consequently not accurately to scale.

The work is performed by a single acting condensing steam engine, the beam of which projects through the end wall of the engine house, so that the outer extremity is over the mine shaft; here also are the timber sheers, for use in lowering the pumps, and during repairs, while they also carry the stationary ends of the radius links of the parallel motion guiding the main pump-rod. This rod is built up of heavy square timbers and extends nearly to the bottom of the shaft;

its weight is largely counterbalanced by a loaded rocking beam, or balance bob, usually arranged at the surface and not as shown in the model.

The lowest pump is of the bucket type at the bottom of which is a strainer, and some little distance above it a box containing one or more non-return or suction valves; above them is the bucket, which also contains valves and is worked by a rod passing up its rising main and connected by bracket pieces to the sides of the main pump rod or spear, and at the top of its rising main delivers into a cistern in the shaft. From this cistern rises a vertical pipe, to the side of which is connected the barrel of a plunger pump; the plunger is bolted to the side of the main pump-rod, while the valve boxes are arranged in the rising main, access being given by side doors. This rising main may extend right to the surface, or to an adit; but, if the lift is excessive, a similar pump takes it to the next stage and so on, thus avoiding excessive pressure or concussion on the valves and pipes.

551. Models of mining pumps. (Scale 1:8.) Made by Carl Schumann, 1851. M.1405.

In each case the pump is of the bucket type, and has a single foot valve at the bottom of the working barrel, while the pump-rod passes up through the delivery pipe. In one of the examples the pump and its pipes are made in cast iron; the latter have socket joints rendered tight by the use of hemp and metallic lead; in the other two examples the pipes are of timber hooped with iron, and are usually made from tree trunks bored out. The various lengths are socketed together and retained by three timber dogs at each joint; the working barrel is in iron, but the valve boxes are in wood and have side doors; in all cases the pumps and pipes are shown supported by timber beams.

552. Cornish pumping engine (working). Lent by Messrs. Harvey and Co., 1862. Plate X., No. 3. M.850.

This is a small example of a type largely employed in waterworks and for mine drainage, and is an improved form of Watt's single-acting beam pumping engine (*see* No. 26). A cylinder is situated under one extremity of the beam and a plunger pump under the other; the air pump, condenser, and feed pump are arranged between the main pump and the beam centre, while on the other side is the plug rod for actuating the cylinder valve gear. Watt's parallel motion is employed at both ends of the beam. The automatic valves of the steam cylinder are three in number, the steam valve, the equilibrium valve, and the eduction valve, while a fourth valve—the main steam valve—is provided for cutting off the supply of steam from the boiler when stopping the engine, etc. The closing of the steam valve, the opening and closing of the equilibrium valve, and the closing of the eduction valve, are all effected by tappets on the plug rod, but the equilibrium and eduction valves are interlocked by the ingenious arrangement of two intersecting quadrants, by which one of these valves when open retains the other closed. The opening of the steam and eduction valves is controlled by a cataract gear, placed below the engine platform and actuated by the plug rod. It consists of a small oil pump, the plunger of which is lifted by the descending plug rod, and is afterwards free to sink except for the oil drawn in, the only escape for which is through an adjustable orifice,

The engine is single-acting, the steam driving the piston down while the lower end of the cylinder is in communication with the condenser. During this stroke the work is done in lifting the heavy plunger, and drawing into the pump a volume of water from the suction main. At its termination the steam and exhaust valves are closed by the tappets, and the equilibrium valve opened, the latter putting the two ends of the cylinder in communication, so that the piston is drawn upward by the weight of the pump plunger, which in its descent also forces the water in the pump through the delivery valves into the rising main. At the completion of the up-stroke of the piston a tappet closes the equilibrium valve, and so by cushioning quietly stops the downward motion of the plunger, when there is an interval of rest until the cataract plunger has descended far enough for it to lift the catches that retain the steam and eduction valves closed, and on these being released the down-stroke at once recommences. The cataract secures that a definite interval shall elapse between the termination of the down-stroke of the piston and the commencement of the next down-stroke, and so gives a very ready and exact means of regulating the number of strokes made by the engine per minute.

Some very large engines of this type have been constructed, one built in 1858 having a steam cylinder 112 in. diam. This example has a 5-in. steam cylinder and a 4-in. plunger, with a stroke of 15 in.

553. Models of Rittinger pumps (working). (Scale 1: 5.) Made by J. Schröder, 1892 and 1901. M.3172.

This class of pump, in which the plunger is stationary and forms a continuation of the rising main while the pump barrel is moved up and down by the spear rods, was introduced in 1849 by Herr P. von Rittinger at some mines near Chemnitz, but the idea had to some extent been anticipated in the "telescope" pump designed by Herr Althans in 1846.

One of the models represents a single-acting pump, and has only two valves, while the other is double-acting and requires three valves. In both cases the rising main is provided with an air vessel and a retaining valve, and terminates in a fixed hollow plunger upon which the pump barrel slides. The lower end of the barrel is formed into a hollow plunger, which works through a gland in the suction pipe, which, in the case of the double-acting pump, is fitted with a suction valve.

In the single-acting example, during the up-stroke of the barrel, the water displaced by the stationary plunger at the end of the rising main is delivered through it, and prevented from return during the downward stroke of the barrel by the retaining valve, the spear-rods, consequently, always working in tension.

In the double-acting pump, during the upward stroke of the barrel, delivery takes place as above, but in the downward stroke the lower plunger, which is of larger area than the upper one, displaces more water from the suction pipe than will fill the space left in the barrel by the withdrawal of the upper plunger, the excess, therefore, passing into the rising main, so that in this pump water is being discharged during both strokes, while, by suitably proportioning the areas of the two plungers, the weight of the spear rods can be employed as in the ordinary plunger pump. External gland packings are used for both plungers, and the valves in the barrels are rendered accessible by side doors.

554. Suction and lift pump (working). Lent by Messrs. Perreaux and Co., 1903. M.3294.

This is a single acting pump for working by hand-power; being provided with a glass barrel, as is sometimes necessary when pumping chemicals, the course of the fluid and the action of the valves can be seen.

During the up-stroke of the piston or "bucket," the water above it is carried upward, while beneath the bucket an empty space would be left, but for the atmospheric pressure which forces the water up the suction-pipe and causes it to follow the bucket. Upon the commencement of the down-stroke the water in the barrel is prevented from returning, by a valve at the bottom of the barrel, but is allowed to pass through the bucket to its upper side, by a valve within it from whence it is delivered at the next up-stroke.

The valves employed in this example are of the construction patented in 1856 by M. L. G. Perreaux, and are made entirely of vulcanised india-rubber. The base of the valve is a stout annular flange, by which it is held, and the passage is closed by two lips with thin edges which are forced together if the pressure above them is greater than that below.

The pump shown is 2·5 in. diam. by 6·5 in. stroke; for larger pumps the Perreaux valve is formed with 3 pairs of lips meeting at a common centre.

555. Model of a reciprocating pump. (Scale 1: 4.) Lent by Messrs. Pontifex and Wood, 1890. M.2296.

Two suction and lift pumps delivering alternately are here arranged in a cylindrical casing in a similar way to that patented in 1793 by Joseph Bramah for a fire engine. The two buckets form a diametral plate and are capable of being oscillated on the axis through 80 deg. by an external hand lever. Beneath the buckets, a sector of the cylinder forms a suction box provided with a suction valve to each bucket.

556. Motion diagram of a compound beam engine. (Scale 1: 12.) Lent by Messrs. James Simpson and Co., 1893. M.2525.

This is a motion diagram showing in section a Woolf compound rotative beam pumping engine. This type is largely adopted for waterworks, and the one shown was constructed in 1882 for the Hammersmith pumping station of the West Middlesex waterworks. Both cylinders are steam jacketed, and have slide valves with back cut-off plates, but the exhaust from the low-pressure cylinder is controlled by separate double-beat valves. A crank and fly-wheel are introduced to give a uniform stroke and to permit of high expansive working. The pump-rod descends from the extremity of the beam some distance beyond the point of attachment of the connecting-rod. Both cylinders are double-acting, and the valve motion is driven from eccentrics on the crank-shaft. With such an engine a duty of over 120 million ft. lbs. has been obtained. The low-pressure cylinder is 47·5 in. diam. with a stroke of 96 in., the high-pressure cylinder 29 in. diam. by 65 in. stroke, and the pump, which is double-acting, is 17·93 in. diam. and 96 in. stroke. The speed is 18 revs. per min. and the indicated H.P. 206.

557. Sectional model of Ashley pump (working). (Scale 1 : 4.) Lent by Messrs. Glenfield and Kennedy, Ltd., 1903. M.3268.

This pump is constructed in the manner patented by Mr. H. Ashley in 1898, by which the whole of the valves of a deep-well pump are rendered accessible for cleaning or repairs without the pump having to be dismantled.

The pump bucket is a long tube forming two pistons connected by a hexagonal waist of smaller diameter. The bottom of the bucket is open, while the top is closed by the delivery valves, which are made as concentric rings surrounding the central attachment for the pump-rod. Each suction valve consists of a rubber disc, which opens against a spring and guard, and is mounted on a seating screwed into the flat faces of the waist; in the pump represented there are six of these valves, two on each alternate face of the waist. The pump barrel forms the bottom of the rising main, and is a casting closed at the bottom, but having inlet ports through its sides at mid-length, while the stroke of the bucket is such that these ports are always between the piston ends. During the up-stroke of the bucket, water flows through the suction valves into the space below the delivery valves, while in the down-stroke the water passes through the delivery valves into the upper part of the barrel from which it is lifted in the next up-stroke.

As the whole of the valves are brought to the surface when the bucket is withdrawn, the usual trouble involved when a suction valve becomes choked is avoided, while the absence of external valve boxes renders this arrangement of pump convenient for placing in bore holes. The large suction valve area that can be provided permits of the pump being worked at a comparatively high speed.

558. Model of a compound pumping engine (working). (Scale 1 : 8.) Lent by Messrs. Hathorn, Davey and Co., 1888. Plate X., No. 4. M.1908.

This represents a modern horizontal compound condensing steam engine, arranged for working vertical pumps situated below the surface in a shaft or well. The weight of the pump-rods is neutralised by suspending them from what is equivalent to an equal-armed lever, so that the rods counterbalance and always move in opposite directions. Such a lever, when provided with an arm for driving from a horizontal rod, was largely used and is known as a T bob; but it is objectionable owing to the large diameter of shaft necessary through the pump-rods being so far apart. In the model, two bell-cranks, arranged oppositely and coupled together at the top, give the same result while placing the pump-rods close together.

The steam cylinders are arranged horizontally and tandem fashion with the high-pressure cylinder in front, the piston-rod of which is connected with a long crosshead. From this crosshead two rods extend backwards, and through passages in the side of this cylinder, to the piston of the low-pressure cylinder. The glands for these rods are at the front of the high-pressure cylinder, instead of in the rather inaccessible position between the two cylinders. From the centre of the low-pressure piston a rod extends backward through the cylinder cover to a double-acting horizontal air pump. This is combined with a jet

condenser in which the exhaust steam from the low-pressure cylinder passes.

The valve motion is known as Davey's "differential," and is an interesting piece of mechanism. The slide valves of the two cylinders are on one rod, which is connected with a "floating" lever. One end of this lever receives a positive motion from the engine crosshead while the other end is caused to reciprocate by means of a subsidiary piston under the control of a "cataract" cylinder. If the crosshead extremity of the lever moves faster than the cataract end, the steam port opening is reduced or closed, so giving increased expansion with lighter loads. Should the load be removed, owing to the failure of the pumps to obtain water or for any other cause, the cut-off and reversal of the valve is so rapid that the pistons never reach the cylinder ends, and in this way many serious accidents to the engines have been avoided.

559. Duplex pump (working). Lent by the Worthington Pumping Engine Co., 1892. M.1910.

In this arrangement of pumping engine, which was originally introduced by Mr. H. R. Worthington about 1850, there are two complete double-acting steam cylinders, side by side, directly working similar pumps, but with the strokes so timed that a practically continuous discharge is maintained into the delivery main, so that the engine will pump quietly even through long lengths of pipe. Each steam cylinder is provided with separate steam and exhaust ports and a short D-slide valve, but the valve of one cylinder is moved by the piston-rod of the other and no fly-wheel is introduced; the delivery is accordingly very uniform, since the resistance due to the head and friction in the pipes alone determines the variations in the speed of the pistons.

560. Steam pump. Lent by J. Cameron, Esq., 1887. M.1878.

This type of direct-acting fly-wheel donkey pump was patented by Mr. Cameron in 1852, and has since been extensively adopted for boiler feeding and similar work.

The steam cylinder is arranged vertically over the pump barrel and the pump rod is attached to an inverted kite-shaped casting which terminates in the pump plunger; within the loop of this casting is arranged a connecting-rod, attached to it, and to the overhanging crank of a fly-wheel shaft, so that direct action is secured while the control of a crank and fly-wheel is retained. The slide valve is worked by an eccentric on the crank-shaft, and the other end of this shaft is provided with another crank working a similar single-acting pump; the cranks are set opposite, so that the pumps deliver alternately. Sometimes double-acting pumps are substituted, while very frequently there are two steam cylinders in the arrangement shown. The pump valve bores are formed in the supporting columns which act as air vessels.

561. Steam pump. Contributed by Messrs. J. Withinshaw and Co., 1869. M.1116.

This simple and early form of the self-contained double-acting steam pump was patented and constructed in 1867 by Messrs. J. Withinshaw and J. E. Baker. The slide valve for the steam cylinder is worked by

a tappet motion from the piston-rod, which is common to both steam and water cylinders; the tappet itself consists of a collar secured to the piston-rod and enclosed in a cylindrical sleeve which is loose on the rod but is provided with caps which are struck by the tappet when near the extremities of the stroke. This sleeve moves a lever connected with the slide valve, and an extension of the lever forms a handle by which the valve can be moved when starting.

The steam cylinder is 5·5 in. diam. and the pump 3·25 in. diam.; the steam chest cover has been removed to render the slide valve visible.

562. Vertical steam pump. Lent by Messrs. Alexander Wilson and Co., 1871. M.2560.

This is a small direct-acting plunger pump, with a fly-wheel for controlling the motion and working the slide valve. The steam cylinder is above, and, on its cover, carries the bearings of the fly-wheel shaft. The piston-rod forms the plunger and is consequently large—thus reducing the steam taken on the up-stroke when but little work is being done. From the plunger projects a form of crosshead sliding on a vertical guide, and from the crosshead extends upward a connecting-rod to a crank-pin on the fly-wheel. At the other end of the fly-wheel shaft is a small overhanging crank, working a block capable of sliding in a slot formed in an extension of the slide valve rod. This arrangement is equivalent to steam distribution by a simple eccentric with an eccentric rod of infinite length. The pump valves are arranged in a valve box attached to the pump barrel.

563. Direct-acting steam pump (working). Made by J. Stannah, Esq., 1891. M.2423.

This machine, patented in 1876 by Mr. Stannah, has the steam-cylinder above, and a single-acting pump below, the large piston-rod being carried down to form the pump plunger. The cylinder, framing, and pump are all in one casting. Projecting from the piston-rod is a stud, on which is a fly-wheel free to revolve. At another point within the fly-wheel is attached the free end of a connecting-rod, the other end of which is capable of swinging on a fixed centre on the cylinder front. As the fly-wheel is driven up and down, the connecting-rod compels it to rotate, and the momentum carries the engines over the dead centres. The motion of the connecting-rod actuates a small cylindrical slide valve by which the distribution of steam to the cylinder is effected. By imagining the connecting-rod to be fixed, and the rest of the engine to be free to swing, it will be seen that the arrangement is equivalent to an oscillating cylinder engine with the steam distributed by the motion of the trunnions.

This example has a 1·75 in. cylinder, ·875 in. plunger, and a stroke of 2·25 in., and is intended to make 110 revs. per min.

564. Steam pump (working). Lent by Messrs. Hayward, Tyler and Co., 1891. M.2374.

This is a small example of a pump for high lifts, fitted with a self-governing gear patented in 1877 by Messrs. E. Cope and J. R. Maxwell and resembling that shown in No. 558. The steam cylinder and the pump

are in line, and from the common piston-rod an arm projects which swings a double lever connected with the valve gear. The main slide valve is above the steam cylinder, and above it again is a smaller slide which is reversed by the motion of the swinging lever, so that when the engine has completed a stroke the small slide admits steam behind a piston combined with a main slide, which is thus forced into the position for the return stroke. The governing is effected by a cataract cylinder moved by the lever. In this cylinder is a small piston connected with the main slide valve, and an adjustable by-pass is provided by which the passage of the oil from one end of the cataract cylinder to the other can be regulated. When the engine moves at above its normal speed the cataract cylinder carries the steam valve with it, and the motion is such as to close the steam port.

565. Direct-acting steam pump (working). Made by J. Bernays, Esq., 1892. M.2433.

This pump, patented in 1884 by Mr. Bernays, is remarkable for the arrangement of crank and connecting rod by which the fly-wheel is connected with the reciprocating plunger, the result being that the stroke of the ram is twice the diameter of the crank path.

The machine is arranged with the steam cylinder at one end, the large piston rod of which is carried through, and forms the plunger of a single-acting pump at the opposite end of the machine. The fly-wheel and shaft with an overhanging crank are placed midway, the crank-pin being connected with a pin on the pump ram by a connecting-rod whose effective length is equal to the radius of the crank-path. This connecting-rod is produced backwards, and terminates in a circular end which engages alternately in two notches formed in a portion of the framing, over the centre line of the fly-wheel shaft. The outer extremity of the short connecting-rod is in this way controlled, and the kinematic chain closed during the time it would otherwise be incomplete. The result is that the throw of the crank is increased by the length of the connecting-rod at each end of the stroke. The adjacent diagram shows the positions of crank and connecting-rod at various portions of a revolution, the connecting-rod being coloured blue, the ram red, and the stationary notches grey.

The admission of steam is controlled by an ordinary eccentric and slide valve, but when required to drive by hand, a handle is inserted in the fly-wheel. The suction and delivery valves are contained in boxes with circular flanges, which can be bolted on to suit a horizontal or vertical arrangement of the pump.

566. Direct-acting steam pump. Made by Messrs. Miller and Tupp. Received 1901. M.3202.

This is a small boiler feed-pump constructed upon a system patented by Mr. J. J. Miller in 1884. The steam cylinder and the pump are a single casting, and the piston-rod forms the pump plunger; on one side of the cylinder is a chamber containing a crank-disc fixed to the shaft of an external fly-wheel, while an eccentric hole in this disc receives the spherical end of a pin projecting from the side of the elongated piston of the steam cylinder. The piston as it reciprocates therefore turns the fly-wheel, and itself undergoes considerable to-and-fro rotation. In the cylinder wall there are two steam ports, and an exhaust

port between them, while the piston has two axial grooves leading to its top and bottom faces respectively, the arrangement being such that the piston, by its rotating motion, acts as its own slide-valve and gives a steam distribution similar to that obtained by the use of an eccentric without angular advance. The cylinder is 1·1 in. diam. by ·68 in. stroke and the plunger is ·56 in. diam.

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567. Working model of water-pressure pumping engine. (Scale 1: 12.) Made by T. B. Jordan, Esq., 1843. M.1413.

This represents an engine in which the energy is supplied by water at a high pressure; it was constructed in 1842 at the Butterley Works, from designs by Mr. J. Darlington, and erected at the Alport Lead Mines in Derbyshire. These mines were drained by an adit level, three miles in length, which delivered into the Derwent all water within 132 ft. of the surface; the engine was then added to pump from the lower levels by means of water received from the rivers Lathkil and Bradford, the used power water being also delivered into the drainage adit. In 1852 the engine was removed to the Tarlargoch Mine in North Wales.

The cylinder is 50 in. diam. by 10 ft. stroke, and the piston-rod passes through the bottom of the cylinder and is directly attached to the spear rods which terminate in a pump plunger 42 in. diam. (*These intermediate rods, which are of wood, are dispensed with in the model.*) The admission and discharge valves for the power water are 22 in. diam. by 22 in. long, with feather edges; but there is also a pair of similar valves 5 in. diam., the object being to avoid concussion by closing the large valves when ·875 of the stroke is completed, leaving the small ones only to be closed at the end of the stroke. The valves are actuated by a tappet motion driven by a rod connected with the top of the piston and guided by a link parallel motion. The supply water is under a head of 130 ft., and the pumps have a lift of 130 ft., the total efficiency of the plant being about 70 per cent.; the working speed is five double strokes per minute, and the discharge 600 gals. per stroke.

568. Working model of water-pressure pumping engine. (Scale 1: 8.) Lent by Messrs. Hathorn, Davey and Co., 1888. M.1907.

This is a pumping engine, by Mr. Davey on the same principle as the preceding. Such engines are frequently employed where water at high pressure is available, as they are economical transformers under suitable conditions. They may be placed down in the workings of a mine without risk of stoppage that might take place by submergence with water.

In the example shown, internal packings are avoided completely by the use of plungers and external glands. The power plungers are in the middle of the machine and stationary, being bolted to a central high-pressure valve box which corresponds with the valve chest of a steam cylinder. Upon these small plungers slide the two large plungers of the pumps. The pump barrels are bolted to the bed plate and the plungers are tied together by two long side rods. At the end of the

pumps are their valve boxes, the delivery boxes being connected by a long horizontal pipe. The engine valves are of the vertical drop type, with the upper stems or guides acting as pistons. The water to and from these pistons is distributed by an auxiliary differential valve gear, worked by a lever connected with the main pumps. From the high-pressure valve box the water passes through the interior of one of the small plungers, so driving the large plunger along and into the pump barrel, the other large plunger making an out-stroke at the same time under the constraint of the tie rods, and also discharging the used high-pressure water displaced by the other small plunger. The valve gear then reverses and the return stroke takes place. The exhaust water from the engine may be turned into the delivery pipe of the pumps and so brought to the surface without further pumping, the power head in which case is only the difference between the two heads of water.

569. Organ blower (working). Received 1897. M.2971.

This is a water-pressure engine designed for working the bellows supplying air to an organ, but the cylinder in its action resembles the steam cylinder of a direct-acting steam pump. The supply of water is controlled by a valve connected with the air reservoir, so that the speed of working is automatically adjusted to the consumption of wind.

The blower shown has a cylinder 5·5 in. diam. by 10 in. stroke, and is fitted with a valve gear patented by Mr. D. Joy in 1874. The piston-rod is directly attached to the bellows, but has on it a tappet which reverses the distributing slide valve on the completion of each stroke. This slide valve is of the piston type, but is in reality two valves combined in one, for by its sliding motion the valve acts as the main slide valve, while by a rotary motion through 20 deg. it acts as a plug valve which does duty as the auxiliary valve. The plug is in the middle of the length of the piston slide, and by its motion lets the water to and from the ends of the chest of the piston valve, so causing the sliding motion of this valve. The rotation of the valve is performed by two inclined horns, secured to the valve-rod and moved by the tappet on the piston-rod. A simple tappet moving a single slide valve will not work at a slow speed without assistance, and it is for this reason that some form of auxiliary valve is almost invariably introduced. A sectional drawing further illustrates the construction.

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570. Drawing of pump bucket. (Scale 1 : 4.) Presented by Messrs. G. J. Worssam and Son, 1904. M.3323.

This bucket was used for a pump 18 in. diam. and 35 ft. lift, worked by an atmospheric engine designed by Smeaton in 1767 for the New River Co. at Clerkenwell. In it was employed the self-adjusting cup-leather packing which appears to have been introduced by Smeaton to replace the leather discs or rings previously used.

The bucket consists of an iron ring with a diametral bar across it, to which is secured a disc forming two leather clacks, each provided with strengthening plates; below this ring is the cup leather and a brass ring, fixed by set screws, which retains it. The lower end of the pump rod is opened into four prongs, which curve outward and are riveted into the main ring; this construction gives larger valves than

are possible with a central rod, and also distributes the stress from the rod.

571. Collection of models of pump valves. (Scale 1 : 12.) Made by T. B. Jordan, Esq., 1844. M.2653–4.

Most of these are large valves intended for use in mine drainage pumps, in which single flap valves would be objectionable owing to the shock on closing through the high lift necessary to obtain the requisite area, and also to the intensity of the pressure upon the seating.

(*a*) This is a double clack or butterfly valve ; the leather disc forms the hinges for two valves and also their working faces.

(*b*) This valve consists of six triangular clacks arranged in the form of a hexagon, the sides of which are formed by the leather hinges. It is a modification of the "bishop's cap" valve, introduced and extensively used by Boulton and Watt.

(*c*) R. Jenkyn's annular clacks. With the object of providing a large area with a limited movement, the valve is made of three concentric portions ; the central clack is hinged to the annular one beneath it, and this to the lower one. These were patented in 1841.

(*d*) R. Hosking's many-seated valve. This is composed of a series of rings working on a vertical guide, each ring having its seating on the ring beneath it. The numerous seatings increase the discharge area with a limited lift, and concussion is reduced by the rings closing successively.

(*e*) N. Harvey and W. West's double-beat valve. This is a modification of the steam valve so long used in Cornish engines. The valve is in the form of a deep ring with a seat at the lower edge, and another seat, of somewhat less diameter, at the upper edge. As the fluid pressure only acts on the difference between the areas of these two portions, the blow on closing can be reduced indefinitely, while, on account of the two seats, the discharge area for a given lift is nearly double that of a simple valve. In the example the lift is limited by a central stop, which acts also as a guide ; it was patented in 1837.

(*f*) J. Darlington's single-beat tubular valve. The valve is in the form of a short cylinder, the lower edge of which beds on an ordinary seating, while the upper portion slides on a central stem, the joint being made tight with metal packing rings. By this arrangement the valve is almost in equilibrium, while only one seat is employed.

(*g*) R. Hosking's double-beat valve is a modification of (*e*). The areas of the two seats are very unequal, so as to ensure rapid closing, and the valve is guided by three pins projecting from its under surface ; these also limit the lift.

(*h*) G. H. Palmer and C. Perkin's elliptical clack. This is an elliptical disc turning on an axis that does not pass through its centre of gravity. The arrangement resembles the old form of throttle valve for a steam engine, and gives partial equilibrium, but does not provide for leakage through wear. It was patented in 1840.

(*i*) Beneath the bench is a full-sized model of a 20 in. double clack valve suitable for low-lift pumps. The seatings meet in a central ridge at an angle of 155 deg., by which device the angular movement of the clacks for complete opening is considerably reduced. The clacks are retained in position by loose hinges, having bushed bearings carried in lugs on the seating casting, and provision is made for securing leather to the valve faces.

For mining pumps, lifting dirty or sandy water, double-beat and other metal-faced valves are not so extensively adopted as they are where pure water only is dealt with; with many makers the tendency is to increase the number rather than the size of the valves employed.

572. Buckets and rods for mine pumps. Received 1865.
M.2781.

In the example for a 10-in. barrel, the bucket is a ring casting with a central cross rib, through a hole in which the pump rod passes before being secured by a cotter below. Above the bucket the rod is spread out, to enable it to secure a leather disc which forms the two flap valves, each of which is strengthened by two metal plates. The circumference of the bucket is packed by a long leather sleeve which acts as a cup leather; it is secured and strengthened below by a wrought iron band held in position by the rod cotter. A portion of the spear rod, together with the conical sleeve coupling by which the interlocking ends of the pump rods are held together, is also shown.

Two buckets 6 in. diam. are shown having leather flap valves, but in one case the bucket is packed circumferentially, in a non-adjustable recess, with marine glue or gutta percha as patented in 1844 by Mr. T. Heaton, while in the other a built-up leather cup is used.

In another example 6 in. diam. the valve is in two portions, a heavy ring and a collar, sliding on the pump rod so that two openings are obtained; the bucket is made tight in the barrel by soft packing which can be tightened by a screwed sleeve below.

In an example 5·5 in. diam. the arrangement is that patented in 1855 by Messrs. M. Kennedy and T. Eastwood, the bucket being packed circumferentially by a single spring ring and centrally by a solid ring which, alternately by the friction of the spring or the pressure of the water, is moved up or down through a travel of ·5 in. at the ends of the stroke; the lower portion of the bucket serves as a seating, and is only 4·6 in. diam.

573. Pump valve. Presented by F. C. Haste, Esq., 1904.
M.3378.

This is a pump valve and box of the form patented by Mr. Haste in 1900. The valve, which is made of "dermatine," is of double conoidal shape and is contained in a box of similar form. It is free to slide axially upon a central spindle supported by webs, and, when closed, seats itself on the curved surface of the box. The water-way past the valve has an area equal to that of the inlet pipe, so that the lines of flow are but little disturbed. This example is arranged as a suction valve.

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574. Bramah's original hydraulic pump and press. Received 1857. Plate X., No. 5.
M.6.

This is the machine constructed in 1796 by Joseph Bramah to demonstrate the principle of his hydraulic press. By exerting a moderate force on a small pump plunger a certain fluid pressure is obtained which is transmitted to a cylinder fitted with a large piston,

and so the force driving the large piston outward is greater than that exerted in forcing the smaller piston down in the ratio of their areas.

The apparatus consists of a stout timber base carrying at one end a cistern, on which is fixed a brass cylinder and a small force pump which draws its water from the cistern and delivers it into the cylinder. A leather-packed piston in the cylinder extends upward to a strong lever which carries at its extremity a weight platform, the leverage being 20 : 1, so that 1 cwt. on the platform is equivalent to 1 ton on the ram. When the pump is worked, a load of 6 cwt. is lifted in the scales, showing an upward pressure in the ram of over 6 tons. There is a small hole on the side of the cylinder which permits the escape of the water if the piston is pumped too high, and a small valve is arranged that permits the water to return to the cistern when it is desired to lower the piston. The pump ram is ·5 diam., and the piston 4 in. diam., so giving an area ratio of 1 : 64. The hand-lever of the pump has two fulcra, but its maximum advantage is about 1 : 18, so that from the hand to the press the total ratio is over 1 : 1,000.

Owing to the difficulty experienced in boring out these closed cylinders when longer strokes were required, a turned ram, working through a leather collar or packing, was soon adopted, and has since remained the usual construction followed when employing hydraulic pressure.

575. Model of hydraulic pumping engine (working). (Scale 1 : 8.) Lent by Messrs. Sir W. G. Armstrong, Whitworth and Co., 1899. M.3083.

When Lord Armstrong introduced his system of hydraulic machinery the pressure water generally used was obtained from the town supply mains, which at Newcastle and several other places are under a head of 200 ft., *i.e.* a pressure of 86 lbs. per sq. in. Owing to the uncertainty of the supply, and for other reasons, water tanks or towers were added, while to give sufficient storage in a situation where the demand for power was very fluctuating, the well-known water tower at Grimsby was constructed, and is still in use, as a means of storing a large amount of water at a considerable head.

In 1851, Lord Armstrong "resorted to another form of artificial head which possessed the advantage of being applied at a moderate cost in all situations, and of lessening the size of the pipes and cylinders by affording a pressure of greatly increased intensity." This was the hydraulic "accumulator" (*see* No. 841), which is a reservoir giving pressure by load instead of by actual head, and consists of a heavily weighted vertical ram of large area lifted by water forced into the cylinder by a pumping engine.

The type of engine first used for this service had a plunger pump at each end of the cylinder, but in the model a single plunger only is used, the work in the two strokes being distributed by the use of two heavy fly-wheels ; two connecting-rods are also employed to balance the stresses. Above the pump are two domes communicating with the suction and delivery pipes respectively, and containing strainers. In a later arrangement the combined bucket and plunger pump was arranged between the cylinder and the crank-shaft, while finally, at the suggestion of Mr. H. Thompson, the clack of the bucket was dispensed with and the valves confined to readily accessible valve boxes.

576. Model of a hydraulic press and pumps. (Scale 1; 4.) Contributed by S. Perkes, Esq., 1866. M.1004.

This represents a double-ended hydraulic press for extracting oil from linseed, cottonseed, or similar material; it embodies some arrangements patented by Mr. Perkes in 1860. The seed is placed in canvas bags which are stacked between recessed metal plates, and the whole mass is then compressed between a pair of opposing hydraulic rams, by the pressure of which the seeds are broken and pressed into a solid cake, the contained oil in the meantime descending into a collecting tray. The pressure is maintained so long as oil is escaping, and when the work is finished the material is in the form of a hard cake, from which the canvas bags are peeled off for further use; such cake is utilised as food for cattle.

The two hydraulic cylinders of the press are connected by three tie-bolts, which also act as supports for the frames containing the seed bags, while by the use of two rams both ends of the stack can be simultaneously worked at when charging or emptying the machine. The return stroke of such horizontal rams is usually accomplished by the aid of chains and hanging weights, not shown in the model.

The water, under high pressure, is forced into the cylinders by pumps worked by double-ended levers; in commencing to press, the largest pumps are used, as there is slight resistance, but as the pressure increases some of the pumps are shut off by valves, and a smaller quantity of fluid is delivered per stroke, but at a higher pressure. The areas of the plungers of the finishing pumps are approximately as 1 : 2 : 3, but owing to the difference in their strokes the volumes they deliver are as 1 : 4 : 9.

577. Model of hydraulic pumping engine (working). (Scale 1 : 4.) Made by the Hydraulic Engineering Co., 1895. Plate X., No. 6. M.2746.

This represents one of the sets of pumping engines employed by the London Hydraulic Power Co. at their central stations. The service of mains is supplied with water from the Thames, which after being filtered is forced by the steam pumping engines into the high-pressure mains; accumulators at the station somewhat steady the demand, and also adjust the speed of the engines to the rate of consumption.

The model has one high-pressure cylinder 5 in. diam., and two low-pressure cylinders 6·5 in. diam., working downward on a three-throw crank-shaft with cranks set at 120 deg. The piston-rod of each cylinder is prolonged downward to form a plunger 1·25 in. diam. working in a single-acting pump barrel secured to the standards. The stroke throughout is 6 in., and the pumps deliver 9 gals. per min. at a pressure of 700 lbs. per sq. in. when running at 120 revs. per min. with a steam pressure of 80 lbs. By the introduction of a crank and fly-wheel a definite stroke and expansive working are secured; the difficulty with the connecting-rods is overcome by forking them so as to clear the plungers.

The later engines of this type differ from the model in having three cylinders of increasing diameters, giving three-stage expansion. The surface condenser is formed in the standards, as so frequently arranged in vertical marine engines.

578. Diagrams of hydraulic power plant. Lent by E. B. Ellington, Esq., 1891. M.2384.

These were used to illustrate a paper read by Mr. Ellington before the Institution of Civil Engineers in 1888, and show the machinery at the Falcon Wharf pumping station of the London Hydraulic Power Co.

There are four sets of pumping engines, each of 200 indicated H.P., of the vertical two-stage expansion condensing type (*see* No. 577).

Steam is supplied by four Lancashire boilers fitted with Vicars' mechanical stokers and a Green's economiser in the back flue. There are five large filters for cleaning the water before it is pumped, and the delivery mains are here provided with two accumulators, each having a ram 20 in. diam., by 23 ft. stroke, loaded with iron slag to a pressure of 750 lbs. per sq. in.

Additional stations with similar but larger plants have since been erected at Millbank, Wapping and City Road.

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579. Chinese bellows from Tien-tsin. Presented by Capt. Laurence Archer, 1862. M.1833.

This is an elementary form of double-acting air-pump, used by the Chinese as a bellows for blowing a smith's fire. As a substitute for a cylinder a nearly rectangular wooden box is employed, and is fitted with a lid by which the interior of the machine is rendered accessible. The piston is of wood, and is made fairly air-tight by packings of paper pasted on. At each end of the working chamber is an inlet valve, consisting simply of a stiff paper flap covering a hole on the inside. Similar valves are placed beneath the pump in the wooden delivery chamber, from which the delivery pipe passes to the fire.

580. Model of ventilating pump (working). (Scale 1 : 6.) Received 1865. M.2613.

This is an air-pump used in the mines of the Harz, and also in Cornwall, where it is known as a duck-machine ; it is employed for ventilating the end of a level or other point which is not reached by natural draught.

It consists of a square wooden box partly filled with water, through the bottom of which a pipe, in communication with the level to be ventilated, passes up to within a short distance of the top and is there closed by a clack opening upward. Inside the fixed box is another of the same shape, closed at the top but open below, and reciprocated by a wrought-iron rod attached to a cross arm on the main pump rod. This piston has two clack valves on the top, opening upward, to allow of the egress of the foul air when it descends ; as it ascends these two valves and the water seal prevent the admission of air except from the working face.

581. Model of a blowing engine (Scale 1: 12) at the Penydarren Iron Works, 1859. M.1753.

This model shows an early form of air-pump for supplying wind to a blast furnace (*see* Part II. of Catalogue).

The blowing cylinder is vertical and double-acting ; the upper valves

are contained in three suction boxes and one delivery box on the upper cover, and the lower valves are similarly arranged on the cylinder bottom, which is supported on an open base. The two delivery boxes are connected by a pipe which leads to the blast furnace; on the pipe a large spherical reservoir of boiler plate, which equalises the fluctuations of pressure and velocity resulting from the intermittent action of the blowing cylinder. In modern plants such reservoirs are not required owing to the large capacity of the regenerators or fire-brick stoves that heat the blast. A weighted safety valve, fixed on the blast main, limits the air pressure. The piston-rod of the blowing cylinder is, by a parallel motion, connected with a beam driven from a horizontal crank-shaft rotated by power.

582. Model of a horizontal blowing engine (working). (Scale 1: 8.) M.2761.

This represents a large blast engine used at the Royal Saxon Smelting Works at Freiberg. It has one horizontal steam cylinder, which drives two double-acting blowing cylinders or air-pumps. Each pump has a crank-shaft and a fly-wheel, and the steam engine acts on a crank that connects these two shafts. The air-pump valves, which are leather flaps swinging on vertical axes, are arranged in the covers of the air cylinders, with the delivery valve boxes beneath. The four delivery pipes connect with a large blast main, carried in a trench below the floor; in similar trenches the steam and exhaust pipes of the engine are arranged.

583. Air compressor with water piston. Lent by T. Hurry Riches, Esq., 1896. M.2960.

The compressor shown is a "wet" one and was designed in 1875 by Mr. Riches for obtaining high pressure in a single operation. The admission and delivery valves are on the top of two boxes rising from the ends of a horizontal compressing cylinder containing water, while at the side of each of these boxes is a small mechanically moved valve by which a little water from an enclosing cup is admitted at each stroke to compensate for that carried away by the air.

584. Model of an air compressor (working). (Scale 1: 4.) Lent by Messrs. G. Scott and Son, 1891. M.2420.

This shows a belt-driven "dry" compressor, in which the desired pressure is attained in two stages, and so resembles a reversed compound engine. It consists of a fixed vertical open-topped cylinder, provided with a suction valve below, and fitted with a plunger driven by a forked connecting-rod from the crank-shaft above. The plunger is water-jacketed, and also bored out internally so as to form a cylinder of a vertical stationary ram fixed to the main framing. This ram, which is hollow, serves also as the delivery pipe. The bottom of the plunger is provided with a valve opening upward, and a similar valve is fitted at the bottom of the fixed ram. During the up-stroke, air is drawn into the cylinder through the suction valve at its base, and on the down-stroke this air is compressed and forced through the valve in the plunger into the interior of the same, where on the next up-stroke it is again compressed by the fixed ram, through the delivery valve

in which it is finally discharged from the pumps. The compressed air is delivered into the standard of the machine, which is utilised as a reservoir, the outlet being at the top. Circulating water, for cooling the air, is conducted through the water jackets of the plungers by two swinging pipes at the sides.

585. Model of an air compressor (working). (Scale 1 : 8.) Made by the Ingersoll-Sergeant Drill Co. Received 1904.
M.3320.

This is a steam-driven "dry" air compressor specially designed for supplying air to mining machines, and was patented by Mr. H. C. Sergeant in 1890.

The steam cylinder is placed near one end of a box bed, and is provided with a Meyer expansion valve, by which the cut-off can be varied from ·2 to ·75 of the stroke. The air cylinder is placed at the other end of the bed, and the two piston-rods are secured to a block to which is attached, by a central pin, a wide crosshead free to adjust itself angularly and laterally. From the ends of this crosshead, return connecting-rods drive crank-pins fixed to a pair of fly-wheels mounted on a transverse shaft behind the steam cylinder, and on this shaft are fixed the eccentrics, which drive the valves through rocking levers; the engine is controlled by a centrifugal governor acting on a throttle valve.

The air cylinder has water-jacketed walls and ends, while its piston is hollow and has the piston-rod attached to one face, while from the other projects a hollow tail-rod forming the air inlet. In each face of the piston a circular channel is turned which communicates with the interior and is fitted with an annular valve of T section, seated on the edges of the channel; these valves are the inlets, and during the stroke of the piston one remains closed by the pressure while the other is admitting air behind the piston. The delivery valves are contained in chambers in the cylinder covers, and are closed by springs; the valves are inserted from outside and the chambers are connected with the delivery by ports in the cylinder casting.

The steam and air cylinders are 14 in. and 14·25 in. diam. respectively, and have a stroke of 18 in. The machine runs at 120 revs. per min., has a capacity of 380 cub. ft. of free air per min., and may be used to compress air to pressures of 50 to 100 lbs. per sq. in.

Rotary Pumps.

586. Model of rotary pump (working). (Scale 1 : 4.) Presented by A. Siebe, Esq., 1872. M.1273.

This garden pump, patented in 1828 by Messrs. H. Marriott and A. Siebe, has a small cylinder revolving concentrically inside a larger one; as it revolves, sliding blades or tongues in it are carried round and draw water in from the suction pipe, which opens into a large cylinder just beyond the point of contact of the cylinder with a curved fixed block inside the large cylinder; the water is forced out at the delivery pipe, which opens out from the large cylinder just before the point of contact with the fixed block. The outer ends of the blades are kept in contact with the casing by a fixed cam inside the revolving drum.

587. Model of Fabry's ventilator (working). (Scale 1: 12.) Received 1859. M.2615.

This form of pressure blower, introduced in 1850 by Auguste Fabry, is used as an exhauster at some of the Belgian coal mines; it has been made of considerable size.

The casing is of masonry, lined with cement, strickled off by the revolving blades where a close fit is required. There are two horizontal axles geared together equally, and each carrying three radial blades of such length that their paths intersect. Air from the mine enters the lower part of the masonry chamber and is scooped outward and upward by the blades. As the blades overlap at the centre they do not carry inward from the atmosphere so much air as they exhaust from the mine, but to prevent air flowing in by this course the blades are provided with transverse blades each terminating in a curved contact piece. These six contact pieces on each revolver between them keep the central passage closed, but the volumes between the radial and the cross blades carry in a quantity of air that detracts from the efficiency of the arrangement; by filling in these volumes the machine becomes a three-lobed example of Roots's blower (*see* No. 591).

Fabry's ventilator was usually made with arms 4 ft. long by 10 ft. wide, and ran at 40 revs. per min.; it is stated that 14 H.P. was required to deliver 25,000 cub. ft. per min., under a resistance of 1·7 to 2 in. of water, and that the total efficiency was about 50 per cent.

588. Model of Lemielle's ventilator (working). (Scale 1: 12.) Received 1865. M.2616.

This represents a form of rotary air-pump introduced by M. T. Lemielle in 1852 for mine ventilation; in practice, however, the machine was arranged with its axis vertical instead of as here shown.

It consists of a cylindrical casing having within it a revolving drum of smaller diameter on an eccentric axis, so that the drum touches the cylinder along one line. Two opposite segments are cut from the drum and replaced by flaps hinged to it along the leading edges; the trailing edge of each flap is connected by a link with a fixed pin that is on the axis of the cylindrical casing, so that this edge of the flaps is retained in contact with the casing. Each flap is kinematically a link in a separate four-bar motion. The air enters by an orifice on one side of the line of contact, and, being carried round by a flap, is forced out through a similar passage on the other side, the volume discharged by each flap per revolution being that of the crescent-shaped space outside the drum—less leakage and a deduction for the unused portion of the horns of the crescent; a modified form of the machine has three flaps.

In an actual example the casing was of masonry 14 ft. diam. by 7 ft. high; the fan made 37 revs., and delivered 25,000 cub. ft. per min.

589. Sectional model of Beale's exhauster (working). (Scale 1: 8.) Made by Messrs. Bryan Donkin and Co., 1892. M.2470.

This model shows a form of rotary pump, patented in 1857 and 1866 by John Beale, which is extensively adopted for pumping gas.

It consists of a flanged casing resembling a cylinder, bored out to a section which is not circular but is obtainable from the cardioid curve. This casing contains a cylindrical drum, terminating in a shaft passing through the end cover and by which the drum can be rotated, while at the other end the drum is guided by a circular recess, in which it works, in the other cover. The axis of this drum is at the focus of the cardioid, so that a diametral plate projecting through the drum is always in contact with the casing at each extremity, although it is being carried round by the revolving drum. This plate forms the piston of the machine, and its middle is formed into two guides, between which slides a block fitted on a stud projecting from the end cover—this fixed stud thus giving the radial motion, independently of the guiding action of the casing.

The gas inlet is near the bottom of the casing on one side, and the outlet on the other, while the drum fits closely to the bottom of the casing, so as to prevent the return of the fluid pumped. These machines are made of large size, some delivering 6,000 cub. ft. when making 60 revs. per min., but a small one for 80 cub. ft. would make 300 revs. per min.

590. Roots blower (working). Received 1876. M.2730.

This is a small blower, with revolvers 3·5 in. diam. It resembles No. 591, except in the construction of the revolvers, which in this example have circular ends, each subtending an angle of 90 deg., and the waists also are largely circular.

There is probably more friction with this arrangement, and some unnecessary churning of the air, so that the makers now chiefly employ the form shown in No. 591.

591. Roots blower. Lent by Messrs. Thwaites Brothers, 1890. M.2300.

This machine is a rotary air-pump first patented by Mr. J. D. Roots in 1866, and is extensively used for supplying the air blast to foundry cupolas, smiths' fires, etc. The internal revolvers resemble pinions with only two teeth, and at each revolution discharge a volume of air equal to that of the portions of the teeth outside the pitch circles. To keep the revolvers in their true positions a pair of equal spur wheels is fitted to the shafts outside the casing. The bearings consist of a phosphor bronze cone keyed on the lower shaft, and a cast-iron gland cone fitting in the end plate of the blower. The wear of the conical journals is taken up by closing in the end glands which act as bearings. The machine is arranged to take in its air through the perforated screens at the top and to deliver through the flanged outlet below; when so running the revolvers at the centre are moving upward. This size will deliver 460 cub. ft. of air at 350 revs. per min.

592. Sectional model of Roots blower (working). Presented by Messrs. Samuelson and Co., 1890. M.2305.

The revolvers of this small example are of the latest shape proposed by Roots, and, with the object of preventing the loss through leakage, are so formed as to obtain a double contact during certain portions of their revolution. The tips of the revolvers only touch the casing and

are not used in forming the central contact, the concave portions being deeply recessed, so that the accumulation of grease or dirt in the hollows shall not cause thumping or unnecessary straining. The large central waist here adopted is to give increased strength at this section. Some of these machines have been worked up to a pressure of 15 lbs. per sq. in.

593. Sectional model of Baker's blower (working). (Scale 1 : 8.) Lent by the Baker Blower Engineering Co., 1890. M.2339.

In this blower, introduced in 1873 by Mr. J. G. Baker, there are three revolving axles. The upper one carries a drum with two projecting radial blades, while the lower ones carry drums which form abutments These abutment drums revolve at twice the speed of the upper drum, and are extensively cut away so that they can clear the blades well as they come round; while at other times they form complete abutments preventing the passage of air between the casing and the upper drum. The drums are kept in their correct relative positions by external spur gearing. The air enters at one side of the machine, and is carried round the top by the blades to the outlet on the other side, where it is discharged under pressure.

594. Rotary pump (working). Lent by Messrs. R. A. Lister and Co.. 1894. M.2689.

This is a small example arranged for driving by belting. It consists of a short cylinder enclosing a cylindrical drum, so carried in bearings that its axis is parallel to that of the enclosing cylinder. The internal drum is in contact with the cylinder at the top, and the suction and delivery orifices open into the cylinder on opposite sides of this line. The drum is cut through by a diametral slot, into which are fitted two blades, mutually forced outward by an intervening spring. As the drum is rotated the blades are kept in contact with the enclosing cylinder, and with the drum divide it into three chambers of varying capacity. The delivery is practically continuous.

595. Rotary blower (working). Received 1900. M.3099.

This is a small example of a power-driven machine for forcing air under a pressure of a few inches of water, such as is required for a smith's blast; it was patented in America in 1888 by Mr. L. C. Crowell.

It consists of a cylindrical casing, having within it a drum placed eccentrically so as to touch along a line, on opposite sides of which are the admission and discharge ports. The drum has four radial slots fitted with plates, which, as the drum is revolved, are pressed against the casing by springs, so that the crescent-shaped chamber is always divided into four or five compartments. The edges of the blades are packed with strips of vegetable fibre.

596. Rotary pump (working). Lent by R. Johnson, Esq., 1891. M.2412.

This pump, which was patented in 1890 by Mr. Johnson, resembles in its mechanism Joseph Eve's steam engine (1825). It has two revolving prisms on parallel axes which are compelled to rotate within

a casing at equal speeds by external spur wheels. The lower revolver is in the form of a cylinder with two projecting ribs or blades, and the upper revolver is a larger cylinder with two recesses which allow these blades to pass. The inlet is on one side of the casing, and the discharge orifice on the other. It is intended that the loss by eddying shall be minimised owing to the continuous course of the flowing water, the lower revolver acting as a piston and the upper one as an abutment. Such pumps have been worked against a head of 180 ft. The small example shown is intended for running at 300 revs. and delivering 12 gals. per min.

597. Rotary pump. Lent by Messrs. Fraser and Chalmers, 1904. M.3338.

This pump is of the type in which a drum with sliding blades revolves eccentrically within a chamber. In the belt-driven example shown the chamber is, however, in halves, each less than a semicircle, as patented in 1897 by Mr. R. L. Gurden, and springs are employed to force out the radial blades or pistons so that they shall remain in contact with the walls of the chamber. In another modification by Mr. Gurden, dovetailed recesses are left in the walls of the chamber for the reception of babbitt metal which can be poured into them and around a core of the required outline so as to obviate machining.

598. Rotary pump (working). Presented by the Albany Engineering Co., 1906. M.3434.

This is a rotary pump consisting of two spur wheels geared together and rotating inside a closely fitting casing. The water enters at one side of the wheels and is carried round the casing and discharged at the opposite side. The method used for preventing leakage was patented in 1904 by Messrs. H. Handoll and R. J. White. Grooves are formed along the edges of the teeth and across the faces in contact with the end covers ; these grooves become filled with water which acts as packing. The axles run in plain bearings formed in the end covers and the driving axle passes through a stuffing-box.

The example shown will raise 500 gals. of water per hour to a height of 100 ft. when running at 430 revs. per min.

Centrifugal Pumps and Fans.

599. Original wheel of the Whittlesea Mere centrifugal pump together with drawing (Scale 1 : 24) of the complete plant. Presented by Messrs. Eastons and Anderson, 1877. M.1732–3.

This early application of the Appold centrifugal pump was made by Messrs. Eastons and Amos in 1852 to drain Whittlesea Mere in Huntingdonshire. The scheme affected an area of 6,600 acres, and was the largest pumping installation undertaken up to that time ; the machinery remained in use till 1877, when it was replaced by a larger plant.

The pump had no casing, as the wheel worked submerged in a cast-iron coffer-dam ; the water entered this by a bell-mouth at each side, and, after passing through the wheel, was delivered between two

diverging discs, which utilised some of the whirling velocity of discharge. The action of the revolving wheel caused the water to rise in the dam until it escaped at the top at the higher level.

The wheel has a central disc and boss of cast iron, while there are two parallel side discs of copper. These are all connected by copper blades of the curved type introduced by Mr. J. G. Appold in 1851, and to which the efficiency of the pump is largely due. The wheel is 4·5 ft. diam. by 15·5 in. face, and weighs 933 lbs. It was directly driven by a horizontal steam engine of 4 ft. stroke, and at 90 revs. per min. delivered 15,000 gals. (*i.e.*, 67 tons) of water per min. against a head of 4 or 5 ft.

600. Centrifugal pump. Contributed by Messrs. Eastons and Anderson, 1876. M.1432.

This is an Appold pump embodying details patented in 1862 by Mr. J. C. Amos.

The casing is of the spiral or volute form with cover bolted on for convenience of access to the wheel in case of fouling. The suction pipe divides into two branches so as to deliver on both sides of the wheel at its axis in order to balance end thrust. The wheel is enclosed by side discs; the vanes are of the curved form determined experimentally in 1849 by Mr. J. G. Appold as being more efficient than the simple radial form. The example has suction and delivery pipes 8 in. diam. and a wheel 14·5 in. diam.

601. Model of centrifugal pump. (Scale 1 : 8.) Lent by Messrs. Lawrence and Porter, 1876. M.2515.

This represents a centrifugal pump with 6 in. pipes. The wheel is of the double disc type and is enclosed in a spiral delivery chamber, the suction entering the disc at the centre from each side. To facilitate the removal of the wheel, and also to simplify the general construction, the pump case on one side is formed with a flange, on to which a closing cover is bolted as patented in 1875 by Messrs. J. E. Lawrence and E. V. Porter. This cover can be removed without disturbing the suction or delivery pipes or removing the spindle.

602. Wade and Cherry's centrifugal pump. Lent by J. A. Wade, Esq., 1890. M.2293.

In the ordinary centrifugal pump the distance passed through by the water while it is under the action of the blades is very limited, so making it difficult to establish the necessary rotary motion without wasting energy through too violently changing the velocity of the water. To obtain a more gradual action the pump shown has the usual wheel, but in addition helical blades are provided which extend into the two branches of the suction pipe, and form extensions of the wheel, as patented in 1884 by Messrs. J. A. Wade and J. Cherry. By these considerable velocity is gradually given to the water before it reaches the wheel, thereby reducing the usual shock on entering. It is stated that these helical blades reduce the speed required for pumping, and that they increase the suction head that the pump will work upon.

The example has pipes 6 in. diam., and a wheel 17 in. diam.

603. Model of centrifugal pumping plant (working). (Scale 1: 8.) Lent by Messrs. J. and H. Gwynne, 1894. M.2567.

This shows a horizontal compound condensing steam engine driving directly a pair of centrifugal pumps, four sets of which, together with 10 horizontal boilers, were erected in 1874–6 to drain the Ferrara Marshes, in Northern Italy. The plant discharges 2,000 tons of water per min., to a maximum elevation of 12 ft., each of the eight pumps having a capacity of 56,000 gals. per min. It is stated that the fuel consumed is 2·5 lbs. per indicated H.P. and 4 lbs. per water H.P., which is equivalent to a duty of 55 million foot-pounds per cwt. of coal.

The steam cylinders are 27·7 in. and 46·6 in. diam. respectively, with a stroke of 27 in., and the cranks are at an angle of 130 deg. Both cylinders are steam jacketed, and the high-pressure cylinder has an expansion valve fitted on the back of the main valve. The exhaust steam passes into two tubular condensers fixed in the delivery pipes, the whole of the water pumped passing through these condensers, which have tubes 3 in. diam. and 750 sq. ft. of tube surface. To clear the condensers a vertical air pump, 19 in. diam. by 12 in. stroke, is provided, and driven by an eccentric situated between the two cranks. The pump wheels are 60 in. diam., and the pipes 54 in., the volute casings of the pumps being 15 ft. diam. in single castings. The sluice gates are worked by hydraulic pressure applied by vertical cylinders. Each of the ten boilers has 730 sq. ft. heating surface and 30 sq. ft. grate area.

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604. Model of ventilating fan used in the Saxon mines (working). Received 1865. M.2614.

This is a small fan, with five radial arms and flat rectangular blades, which revolves within a casing about 4 ft. diam. The air is taken in at the centre of each side by a pipe 20 in. diam., and is discharged at the circumference through a rectangular tube 15 in. by 10 in., to be conveyed through wooden or zinc pipes to the working face. The fan is driven by a belt kept tight by a tension pulley, and makes 16 revs. for one of the driving wheel.

A similar fan used in the Saxon mines had blades 8·5 in. sq. and a diameter of 2·5 ft. It could be driven by one man at 400 revs. per min.; the pipe was 6 in. sq. and 60 cub. ft., *i.e.*, the estimated quantity required by ten miners, were drawn by it from a distance not exceeding 440 yards.

605. Exhausting fan. M.2783.

This is a small centrifugal fan arranged for driving by belting. The air enters the fan through two passages formed in the base, and is delivered between the two enclosing side plates. The fan consists of a central disc from which project on each side eight blades, curving backward.

606. Air propeller. Lent by the Blackman Air Propeller Ventilating Co., 1890. M.2295.

This machine is specially intended for moving large quantities of air against a slight resistance as required for ventilation, drying, etc.; it operates by a scooping action, and passes its air parallel to the axis

of the machine, thereby greatly differing from a centrifugal fan. The form of the eight sheet-metal blades is such as to give about 70 per cent. more collecting than delivering area. To ensure the true alignment of the two bearings, they are carried in spherical sockets.

The example shown is 18 in. diam., and is intended, when running at 1,200 revs. per min., to deliver 4,000 cub. ft. of air, but similar propellers are made up to 7 ft. diam., with a delivery of 100,000 cub. ft.

607. Model of ventilating fan. Received 1902. M.3262.

This fan is of the centrifugal type, and embodies details patented in 1887 by Mr. N. Chandler; it has blades, slightly S-shaped, projecting from the sides of a central disc on a spindle carried in bearings placed outside the sheet steel casing, by which the air is led, from passages below communicating with the mine, into each side of the fan, thus avoiding end thrust. A volute casing and expanding outlet cause some of the velocity energy of the air on leaving the blades to be converted into pressure energy. An actual plant of this construction, with an engine, such as No. 95, having cylinders 16 in. and 24 in. diam. by 16 in. stroke, driving a fan 15 ft. diam. by 6·5 ft. width, at 151 revs. per min., indicated 117 H.P., and passed 173,000 cub. ft. of air per min., against a pressure of 3·1 in. of water.

608. Sirocco fan. Lent by Messrs. Davidson and Co., 1901. M.3191.

This construction of centrifugal fan was introduced in 1898 by Mr. S. C. Davidson, as the result of a series of experiments made with the object of reducing the eddies which he considered existed near the after-face of blades of the ordinary type.

The "Sirocco" fan has usually from 32 to 64 blades, of a radial length of from ·1 to ·06 of the diameter of the rotary portion, and an axial length of ·6 diam, thus forming a hollow cylinder which has a disc and shaft at one end while the other end is completely open for the entrance of the air. The fan is arranged in a spiral casing of rectangular section, carrying on one side the open frame containing the bearings. The blades are made from sheet metal stampings, pressed to shape, and are riveted to the end disc and a connecting ring. Their acting faces are concave, and so set that they scoop in the air and deliver it tangentially with a velocity that is estimated to be 1·8 times that of the periphery of the fan. To this innovation is probably due the relatively high pressure given by the fan when compared with its speed.

The example shown has a fan of 5 in. diam., but an adjacent photograph represents a similar fan of 35 in. diam. directly driven at 450 revs. per min. by an electric motor. The output is stated to be 23,000 cub. ft. of air per minute, against a water gauge pressure of 1·5 in., with a consumption of 9 electrical H.P. Another photograph shows a larger fan, directly driven by a steam-engine, and supplying forced draught to a marine boiler working with closed ashpits.

Rams.

609. Hydraulic ram. Lent by John Blake, Esq., 1889. M.2285.

In the modern example shown the drive pipe bolts on to the lower 5 in. flange, and the 1·25 in. delivery proceeds from the stop valve, while the three cocks provided are to facilitate emptying the air vessel and pipes. The valve which suddenly stops the flow is formed like a square box, with concave sides finely perforated, which fits into the base of the machine. A number of india-rubber bands are sprung over this box, the concave sides leaving some distance between the grid and the rubber. The drive water rushes through the perforations and runs to waste through the central outlet until its velocity is sufficient to drag the rubber with it, and so close the overflow. The consequent rise of pressure forces some of the arrested water through a valve into the air vessel, from which it is steadily delivered at the high level by the pressure of the compressed air. Four arms are provided by which the distance between the rubber rings and the sides of the box can be adjusted from the outside to obtain the best results with various rates of supply.

610. Hydraulic pumping ram. Lent by H. P. Vacher, Esq., 1903. M.3310.

This ram is arranged for utilising the energy of a stream of possibly impure water for pumping clean water from some other source.

The impulse portion consists of a lower casing with an attachment for a drive pipe, and a pulse valve of a form patented in 1898, by Mr. R. C. Green, in which a rubber disc with a central hole is suspended below a concave grating which serves as a seat. The drive water flows away through this valve until its velocity becomes sufficient to bulge the rubber on to the grating and thus close the outlet. Above this portion and in communication with the drive pipe is a vertical cylinder fitted with a spring-loaded piston, which is attached to the piston of a single-acting force pump arranged above it and combined with an air vessel. When the column of water in the drive pipe is suddenly stopped, through the closing of the pulse valve, the accumulated energy is largely utilised in performing the delivery stroke of the pump, which forces water into the air vessel, and also compresses the spring; when the shock has passed off the pulse valve opens, by its elasticity, and the return or suction stroke of the pump is performed by the helical spring. The pure water is admitted to the pump by a suitable suction pipe, and the delivery takes place continuously from the air vessel through a similar pipe. To prevent noise the pump valves are also made of rubber.

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611. Pulsometer. Lent by the Pulsometer Engineering Co., 1876. M.2516.

This greatly improved form of Savery's pumping apparatus of 1698 (*see* No. 7) was invented by Mr. C. H. Hall in 1872. It lifts water by the partial vacuum resulting from the condensation of steam in a closed chamber, and then forces up the water by the pressure of steam introduced into the chamber.

It consists of a casting forming two working chambers and a central chamber that acts as an air vessel. One chamber is taking in water while the other is discharging it, and so a nearly continuous delivery is obtained which is further improved by the air vessel. The two working chambers unite at the top in a steam chest containing a ball valve which can roll to either side, and so stop the admission of steam to either of the two chambers. At the lower portion of each working chamber is a suction and a delivery valve for water, and the boxes of these valves are respectively connected with the common suction and delivery pipes. The two suction valves are arranged together, so that a single ball suffices for the two seatings, but at the lower end of the suction pipe a foot or retaining valve such as the Perreaux valve (*see* No. 554) and box (shown separately) is also usually added if the suction height is considerable. The great superiority of the machine over Savery's consists in its being automatic in its action, a result that is obtained by the sensitiveness of the steam ball valve. This valve, when closing one side, is so close to its other seating that the sudden rush of steam that takes place, as soon as all of the water has been sent through the delivery valve, pulls the ball valve on to the previously open port or seat. Steam then enters the other chamber and proceeds to drive out the water that has there been drawn up, while condensation proceeds in the opposite chamber, which therefore commences to fill.

In a later form economy in steam is effected by the "Grel" arrangement.

612. Water-lifting apparatus. Lent by Messrs. Körting Bros., 1888. M.1896.

This apparatus for raising water, introduced by Mr. Körting in 1885, called the "aquapult," is, like the pulsometer, a practicable and successful development of the principle employed in a crude form by Savery in 1698.

In the aquapult, as in the pulsometer, a succession of strokes or pulsations effect alternately the drawing in of water, through a suction valve, and its discharge through a delivery valve into a rising main. A conical valve at the top of the vessel or chamber admits steam at intervals; the valve closes automatically, and the steam in the chamber becomes condensed, forming a partial vacuum, which draws water through the suction valve into the chamber. Steam is again admitted by the opening of the conical valve, and, pressing upon the water, forces it out through the delivery valve into the rising main, this steam being then condensed, and so on. A little air is drawn in through a very small valve, while the water is drawn through the large valve; this air forms a partition between the water and the incoming steam, tending to protect the latter against immediate and premature condensation. A perforated injection pipe is provided to accelerate the condensation at the proper time.

613. Model of air-lift pump (working). (Scale 1 : 20.) Made in the Museum, 1903. M.3301.

The fact that the pressure at the base of a column of water containing air, in bubbles or otherwise, is less than with a column of water of the same height was observed in 1797 by Löscher, but his

experiments received no practical application till 1846, when Crockford applied the principle to the raising of petroleum from the wells of Pennsylvania. In France the apparatus, under the name of an "emulseur," was used in 1886 by Gondry for raising sulphuric acid, but the recent and more extensive adoption of the air-lift pump dates from about 1893 and is largely due to the labours of Dr. J. G. Pohlé and Mr. J. E. Bacon.

The appliance consists of a vertical pipe reaching below the surface of the water to a depth about equal to the height above the surface to which delivery is to be effected, and of a separate pipe by which air is discharged into the rising pipe at its lower end, thereby reducing the density of the column within it so that, by the external pressure, water is forced to the top and escapes with the air at the delivery end. The system has a low mechanical efficiency but has the merit of being able to deal with gritty water or with chemicals, and the cooling action of the expanding air may be an advantage. It has been found in practice that the depth of the air nozzle below the level of the water in the well should be about 1·5 times the height of the point of discharge above, but the arrangement will work with less submergence; in an artesian well in which the water when tapped rises considerably, this submergence is obtained without additional boring.

The model shows the general arrangement of a plant erected in 1893 at Zwickau, in Saxony, to supply a yarn spinning mill. The water from a stream is allowed to flow into a brick chamber, in the middle of which is sunk a tube-well to give the necessary submergence for the pipes, and is raised by the air-lift into an open tank over the well; from this it flows by gravity into a service reservoir 13·5 ft. lower and more than half a mile distant. The submergence is 63 ft., the lift 45 ft., the rising main 7·5 in. diam., and the air supply pipe 5 in. diam. At a test in 1898 the discharge was 900 gals. per min., while the volume of air required, measured at atmospheric pressure, was 2·73 times this amount; the compressor, situated at the mill, delivered at 30 lbs. pressure above atmosphere, and the efficiency, reckoned from the work done by compressor to that of the work done on the water, was 28·8 per cent.

In the model a simple nozzle is used for the air jet, but in the actual pump a special box, shown in the attached drawing, was found to be more efficient. In Mr. Bacon's construction of air-lift, the air supply pipe encloses the rising main; in some other arrangements the air pipe is carried within the rising main, but this, although convenient, entails unnecessary frictional resistance.

INJECTORS AND OTHER INDUCED CURRENT APPLIANCES.

When a current of air, water, or other fluid is moving through a mass of fluid at rest, some of the stationary particles are carried along by the stream, the internal friction and inter-mixing creating what is described as an "induced current." With suitable vessels and orifices, the mass of fluid carried away by the induced current may result in the formation of a partial vacuum within the vessel, or else, by the use of a diverging tube, the velocity conferred may be

converted into an increase of pressure. The exhausting action of these currents was known as early as 1719, but the first useful application seems to have been made in 1803, when Trevithick caused the exhaust steam from the cylinder of a locomotive to pass up the funnel, thereby greatly increasing the steaming power of the boiler owing to the improved draught through the fires resulting from the reduction of the air pressure in the furnace. Many applications of the principle have been adopted since then, amongst which may be mentioned steam jet exhausters and blowers, while a large number of ventilators have been constructed in which the wind is used to remove vitiated air by the same action. One of the most recent applications of induced currents is found in the liquid fuel apparatus, in which a steam jet breaks a stream of petroleum into a fine spray and carries it with a suitable current of air into the furnace of a steam boiler.

If the inducing current is of water and acts upon some surrounding liquid the arrangement is known as a " jet pump " ; such a machine was used by Professor James Thomson to lift water from a marsh by the energy in a running stream. In the fire-hydrant of Mr. Greathead a jet of high-pressure water is similarly used to give increased energy to a stream of water discharged from a low-pressure main.

The most useful and interesting apparatus of this class is, however, the injector boiler feeder, invented by M. Giffard in 1858 and introduced into England in the following year. Although as a general water-lifting machine it is not at all economical, yet for boiler feeding, where the heat absorbed by the water is not lost, it is a most perfect appliance, provided the feed water is not originally very hot. When the invention was first announced it was generally discredited, as it appeared impossible that a jet of steam could force itself, together with much additional water. back into the boiler from which the steam issued, the vastly greater velocity of efflux of steam particles than that of particles of water under the same pressure, being overlooked. It was soon afterwards proved, however, that not only would the injector feed the boiler from which it received its steam, but it would feed a boiler working at a much higher pressure than that from which its steam was derived.

From 1867 to 1880 various proposals were made for working injectors by exhaust steam assisted by a little boiler steam ; but in the latter year Messrs. Hamer, Metcalfe, and Davies introduced the " split nozzle " injector for working entirely by exhaust steam, and since then this class of injector has been extensively adopted, although for high pressures an assisting jet of live steam is generally necessary. Many improvements in detail have also been made in both classes of injector with the object of making their starting more certain, as considerable difficulty was at first experienced in getting them to commence working, particularly if any lifting had to be done ; other improvements were made to insure the apparatus restarting should it momentarily fail. Although the injector is

entirely relied upon on locomotives and for many stationary boilers, in the Navy, feed pumps are invariably used for regular work.

The "ejector condenser," patented by Mr. A. Morton in 1867, is a form of exhaust steam injector in which the energy of the steam is used to carry the condensing water out of a chamber representing a condenser, and in this way maintains in the exhaust pipe a partial vacuum, which assists in propelling the piston in a similar way to a condenser of the ordinary type.

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614. Model of a jet pump. Lent by Prof. James Thomson, 1876. M.1768.

This form of pump was designed by Prof. J. Thomson for the drainage of land where a small quantity of water, with a moderate fall, is available; by the apparatus the water can be used to elevate a much larger quantity to a lesser head. The arrangement was brought to a practical success at Ballynure, Ireland, in 1852.

There are no moving parts, the machine acting by sending the driving water in a vertical jet downward through a hollow cone connected with the water to be lifted. The combined jet then enters an expanding tube by which the velocity energy is gradually converted into pressure sufficient to elevate the whole mass. There is a loss of useful energy in the arrangement which will be serious or otherwise according to the conditions.

The jet pump, while working, must always have its full supply of water, and so for varying demands is arranged to work intermittently when the supply is below the maximum. This is accomplished automatically by storing the driving water in a reservoir or tank, which, when full, rapidly empties itself by means of two syphons.

In the model the supply of driving water is in the upper tank, which, by the double syphon arrangement, is, when full, rapidly emptied into the lower overhead tank. From the bottom of this tank projects the jet pump, which delivers into a lower tank provided with an overflow. The water to be lifted by the inductive action of the jet enters by the indiarubber tube, the lower end of which is inserted in it.

615. Steam jet pump. Lent by Messrs. S. and E. Ransome and Co., 1887. M.1863.

The suction and delivery pipes are in line, while the steam jet is introduced by a side branch, as shown in the attached sectional drawing. The limit of the suction lift is stated to be about 25 ft. As a pump, such an apparatus is not economical unless use is made of the heat given to the water, as in feeding boilers, or where hot water is required.

616. Model of Boyle's ventilator. (Scale 1 : 24.) Presented by Messrs. R. Boyle and Son, 1898. M.3018.

This apparatus is a form of jet-pump, in which the inducing currents of air are due to the passing wind; these currents are so directed as to carry away with themselves, in their passage through the ventilator, a quantity of the vitiated air from within the building. Fresh air, to

replace the air removed, enters the building from below the floor, but is delivered high above the floor level through vertical pipes, by which means the formation of cold draughts is avoided. The model has, in the inlet and outlet tubes, tufts of cotton wool, which will indicate the action of the ventilator when it is blown across.

The ventilator consists of a fixed metal casing with four vertical orifices, and within it are curved vertical guides, which leave spaces between them that directly communicate with the ventilating shaft from the roof of the building. The passing wind, in travelling between the external cases and the vertical guides, has an inducing action, while the formation of the guides is such that the direct entry of air between them is greatly restricted by the form of the passages. By this arrangement the exhausting action of the two or more acting passages is made to exceed greatly the opposite action of the remaining ones.

617. Model of Cooper's ventilator. (Scale 1 : 16.) Presented by Messrs. Thos. Ash and Co., 1899. M.3061.

This construction of fixed ventilator was patented by Mr. G. Cooper in 1893. Its exhaustive action is due to the readiness with which a moving stream of air will carry with it some of a surrounding mass of stationary air, provided that the contact is suitably arranged and the resulting stream properly directed.

The apparatus consists of an open vertical pipe surmounted by seven segmental transverse wings or shields, each having a segmental orifice between it and the one above it; these passages are somewhat tapering. From whatever direction the wind blows, the quantity of air exhausted from the apparatus exceeds that entering, the difference always creating an up-draught in the vertical pipe.

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618. Giffard's injector. Contributed by Messrs. Sharp, Stewart and Co., 1864. M.364.

This is the original form of the injector, introduced by M. Giffard in 1858, for supplying the feed water to boilers without the use of a pump. Although now adopted generally, it was for feeding locomotives that the great value of the apparatus was first fully appreciated, and on such engines feed pumps have been entirely replaced by injectors. The construction of this machine is best shown in the succeeding example, No. 619.

619. Giffard's injector. Contributed by Messrs. Sharp, Stewart and Co., 1875. M.364A.

This is a sectioned example of an injector following very closely the arrangement described by M. Giffard in his original patent of 1858 for "Improvements in Feed Apparatus for Steam and other Boilers, which improvements are also applicable to the raising and forcing of fluid."

Steam from the boiler is admitted into the apparatus through the inlet marked "steam," and a supply of water is laid on to the other inlet marked "water"; the outlet at the end is for the passage of the water that is being forced into the boiler, while the "overflow" outlet is provided for the escape of any water or steam that may accumulate

in the apparatus when it is working imperfectly, as when starting. The live steam passes through the annular space between the solid cone and the conical nozzle, and thus issues as a fine hollow conical jet, moving at a high velocity; the particles of steam drag with them some of the surrounding air, thus causing in the enclosing space a reduction of pressure, so that the supply water enters by the atmospheric pressure. When thus started the water continues to flow and the steam of the jet condenses within it, thereby giving it sufficient velocity to force its way through a check-valve into the boiler. The various nozzles of the apparatus are capable of independent adjustment, since if too much water be drawn in by the inductive action of the steam jet, the combined stream will not have sufficient velocity to force its way into the boiler.

The action of the injector is more fully realised when it is remembered that the steam from a boiler issues into the atmosphere with a velocity that may be fifteen times as great as that of a water jet from the same boiler; this steam may, however, be condensed in five times its weight of water, so that after the distribution of the momentum of the steam jet into the mass of the combined jet a final velocity more than double that of a simple water jet from the boiler is obtained. This high velocity energy is converted into pressure energy more than sufficient to overcome the boiler pressure, by the slight divergence of the combining or delivery cone, which acts as a Bernoulli tube.

620. Compound injector. Lent by Messrs. Körting Bros., 1885. M.1624.

This construction of double injector was patented by Mr. E. Körting in 1873 and 1876. It consists of two slightly different Giffard injectors (*see* No. 619), arranged in series, so that the first, or lifter, feeds the other, or forcer, which delivers into the boiler. The delivery chambers of both lifter and forcer communicate with the overflow pipe by a three-way starting cock; the latter and the two conical steam valves are manipulated by a single hand lever. When starting, the lever is moved through a part only of its travel, thus slightly opening the steam valves and at the same time opening both delivery chambers to overflow; the arrangement then readily lifts water by its steam exhauster action. The handle is then moved right over, so as to open fully both steam valves and close completely the overflow, after which the forcing injector feeds into the boiler.

621. Compound injector. Lent by the Hancock Inspirator Co., 1887. M.1849.

This form of double injector was patented by Mr. J. F. Hancock in 1876–77. It consists of two Giffard's injectors (*see* No. 619), arranged in series, so that the first acts as a lifter and the second as a forcer, an arrangement that facilitates starting. The forcer valve at the top admits steam to the second injector, and there are two overflow valves, the upper one when open allowing the water and condensed steam from he lifter to pass direct to the overflow. In a modification of the above by the same makers, all the valves are actuated by a single lever.

622. Exhaust injector. Lent by Messrs. Davies and Metcalfe, Ltd., 1902. M.3255.

This is a sectioned example of the injector patented by Messrs. Hamer, Metcalfe, and Davies, in 1877–80, in which, by an important modification in the usual construction, self-starting is secured and the apparatus is enabled to work with the exhaust steam from an engine, instead of requiring live steam from the boiler.

The injector consists of a cast-iron casing containing the usual three nozzles, the steam nozzle, however, being exceptionally large on account of the large volume of steam to be passed, and having a conical spike in its centre to assist in concentrating the steam. The combining nozzle is the leading feature, however, as it is split or divided into two parts over a portion of its length by an axial plane, and one of these parts is hinged to the main portion at its upper end, so as to become a movable flap. The combining and delivery nozzles are connected together, and the water supply orifice beyond them is rendered adjustable by means of a nut at the delivery end. The overflow pipe has a chamber with a partition across it, which forms a water seal, and so prevents the entry of air into the combining cone.

When starting, the steam and water escape freely into the over-flow by the open flap, but when the combined jet acquires such a velocity as to be capable of feeding the boiler its exhaustive action becomes sufficient to close the flap, so that the water passes into the boiler through the delivery pipe.

These injectors will, with exhaust steam, feed against a pressure of about 75 lbs. per sq. in.; if required to supply a boiler at a higher pressure, an extra steam nozzle, supplied with boiler steam, is added to assist in the work; or else a supplementary injector supplied with boiler steam is used, which takes the water, already heated and raised to a considerable pressure by the exhaust injector, along into the boiler.

623. Exhaust injector. Lent by Messrs. Holden and Brooke, 1888. M.1918.

This is a sectioned example of an injector patented by Messrs. Holden and Brooke in 1884, and is specially constructed and proportioned for working with the exhaust steam from an engine, instead of requiring live steam from the boiler. The principle is the same as that of the ordinary Giffard's injector (*see* No. 619), but the details are modified to suit the lower pressure of steam employed; the apparatus is, however, even more remarkable than the original form, since by it the exhaust steam forces the feed into the boiler against the full steam pressure.

A large annular conical nozzle is provided for the steam jet in consequence of the great volume of low-pressure steam. In starting, the steam and water escape freely by an opening in the combining tube and through a clack-valve to the overflow; when this jet acquires the necessary velocity to enable it to enter the boiler, the accompanying exhaustive action causes the overflow clack to close. The injector is self-starting, as the overflow automatically opens when feeding ceases.

624. Restarting Injector. Lent by Messrs. Gresham and Craven, 1887. M.1848.

This is an injector patented by Mr. J. Gresham in 1884–5, in which there is a fixed steam nozzle and no hand-controlled valves, the arrangement being automatic in its starting adjustments. This is accomplished by forming the combining cone as a separate piece free to slide in a bush, so that it acts as a valve of short lift. In starting, the mixed water and steam escape through the overflow until the mixture has acquired a velocity sufficient to enable it to enter the boiler; then the reaction forces the valve upward, thus closing the overflow.

In this construction the cones can be removed for cleaning without breaking any pipe joints, an arrangement introduced by Mr. Gresham in 1877.

625. Ejector condensers. Lent by Messrs. A. F. Craig and Co., 1901. M.3188.

These are sectioned examples of the original form of the modification of the injector introduced in 1867–69, by Mr. Alexander Morton, as a means of condensing the exhaust steam of an engine and at the same time obtaining a considerable degree of vacuum—the apparatus performing the duties of both condenser and air-pump.

The smaller specimen is a model of a condenser for a double cylinder engine, the exhausts from which enter by separate side pipes into superposed cones, while the condensing water enters by an upper pipe and is delivered as a central jet, passing through the exhaust steam space and entering an expanding delivery pipe. The steam in approaching the jet has considerable downward velocity, and the momentum it thus introduces into the water carries the mass into the delivery pipe, where the velocity energy is converted into pressure energy. As, however, the pressure at the outlet is only that of the atmosphere, the lower pressure is much less, so that a partial vacuum is maintained. Within the water cone is an air-jacketed nozzle, by which a jet of live steam can be introduced for starting the apparatus.

The larger example shows a later form, in which an adjustable central jet of live steam does any lifting of the cooling water that may be necessary, or supplies the energy that may be required for an improved vacuum. A closed chamber and a hollow cone are also added, by which any portion of the combined jet which may be too feeble to pass into the diverging tube is carried back into the jet, to be again exposed to the exhaust steam; at the same time it checks the ordinary supply of injection water until the apparatus is again clear.

626. Ejector condenser. Made by Messrs. Körting Bros., 1893. M.2523.

This is an apparatus patented in 1882 by Mr. E. Körting, for condensing the exhaust steam from engines by direct contact with the condensing water, the action resembling that of the injector, except that the energy is used to carry the water out of the condenser against the atmospheric pressure instead of being used to force water into the boiler against the steam pressure.

It consists of a series of nozzles discharging into an expanding tube

as in the ordinary injector, but a large number of drilled holes pointing in the direction of the flow permit of a further addition of steam to increase the velocity. An internal sliding tube adjustable by a hand lever, permits of the covering of these holes when starting, and of their being set in the position of maximum efficiency, as indicated by a vacuum gauge, when on regular work. The condensing or injection water enters at the top, and passing through the water nozzle has its velocity increased on entering the condensing tube, which is in the exhaust steam space, by the condensation in it of the steam. This velocity is further increased by the jets of steam entering through the inclined side holes. The condensed steam and the water rush downward to the outlet from which they can be carried to a cooling pond or elsewhere. At the top is a small nozzle by which a jet of live steam can be introduced at starting, so as to lift the injection water and prime the apparatus.

APPLIANCES FOR COLLECTING, PURIFYING AND DISTRIBUTING WATER.

Where the population of a district is scanty, the water required for individual wants is usually obtained directly from streams, shallow wells, or tanks; but, in a town, the natural supply is generally insufficient and is also liable to serious contamination. Owing to these causes a time arrives in every growing town when it becomes necessary to construct special works for getting water either from deep wells, by the filtration of suitable river water, or from the open country at a distance. The remains of large tanks in India, and of aqueducts in Persia, Italy, and elsewhere, show that important works for providing water were undertaken in very remote periods on an extensive scale.

In Europe during the middle ages, however, the artificial supply of water was entirely neglected, even the aqueducts of earlier times being allowed to fall into decay, so that the present works are of comparatively recent date.

In most countries the smaller cities now depend for their water supply upon wells and cisterns, whilst the larger ones employ lakes or reservoirs supplied from springs and rivers. Where the source of supply is at a sufficient elevation, aqueducts for the conveyance of water have to a great extent been avoided by the use of cast iron or built steel pipes, whilst to guard against accidents and insure a constant supply, additional "service" reservoirs have been introduced.

Waterworks, as the term is now generally understood, for the supply and distribution of water to villages and towns, practically originated at the beginning of the nineteenth century, although some slight efforts in the same direction had been made at very early periods (*see* p. 276). The first pipes used for distribution purposes were made of wood, stone, or earthenware, but where the pressure was considerable the Romans used pipes constructed from sheet lead with soldered joints. In London there was a limited system of water distribution in use from about 1600 to

1820 by means of wooden pipes, of which specimens still continue to be unearthed; they were made of tree trunks, bored through the centre and jointed together by tapering and bell-mouthing adjacent ends, the house connection with the main being made by a tapered pipe of metal driven through the wood. Cast iron pipes with flange joints were occasionally substituted from about 1750; shortly afterwards similar pipes with socketed joints were also tried.

The modern practice is to connect the branch mains with the service reservoir by cast iron pipes fitted with socket joints, and to connect the houses with the street mains by squirted leaden pipes, the latter material giving much easier bends than are obtainable by iron fittings, and possessing greater durability; from the days of the Romans, however, there seems to have been some doubt as to whether under certain conditions lead pipes might not injuriously affect the water.

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627. Model of Norton's tube-well driving apparatus. (Scale 1 : 2.) Lent by Messrs. Le Grand and Sutcliff, 1892. M.2435.

The tube-well consists of a pointed iron pipe with numerous small holes near the end, which is driven into the ground until a water-bearing stratum is reached, more lengths being screwed on as necessary. A small pump is then attached by which the water is brought to the surface. The method is believed to have been invented by Col. Green, of New York, in 1862, but such wells are frequently known as Abyssinian wells, owing to their being first extensively adopted during the British Expedition of 1868.

Norton introduced the arrangement for driving shown in the model, in which a steel clamp is bolted to the tube for the purpose of receiving the blow of an annular driving monkey. By means of ropes passing over sheaves at the top of a tripod, the monkey is raised, and, sliding on the tube as a guide, is allowed to fall upon the clamp, and thus drive the tube into the ground.

628. Model of tube-well driving apparatus (Scale 1 : 2.) Lent by Messrs. Le Grand and Sutcliff, 1892. M.2436.

In this arrangement the driving monkey is guided by the inside of the well tube. A steel cap is screwed on the top of the tube, and receives the blow of the monkey, which has a guide rod entering the tube. For small tubes, as in the model shown, the monkey is lifted by the upper portion of the guide rod, no guide or tripod being required, but heavy monkeys for driving large tubes are raised by a rope or chain gear.

With such apparatus a 2-in. tube well was driven at Norwich to the exceptional depth of 187 ft., the monkey employed weighing 103 lbs.

629. Sectional model of rain-water separator (working). (Scale 1 : 4.) Lent by C. G. Roberts, Esq., 1891. M.2416.

This shows an automatic apparatus patented in 1883–5 by Mr. C. G. Roberts, for separating the first portion of the rain water, coming from

a roof during a shower, from that afterwards falling. It is stated that in the country one gallon per 100 sq. ft. of collecting area is necessary to cleanse the roof and gutters, and double this quantity in cities. The machine is adjusted so that the desired amount of cleansing water shall be rejected, or run into a tank for impure water, the rain falling afterwards being delivered into the clean water storage tank.

The separator consists of a sheet metal casing, provided with a pipe above, through which all the water from the roof enters. In the middle of the case is a drum capable of swinging on a horizontal axis, and provided below with two discharge outlets, the right-hand outlet being the main one. Below the drum is a chamber divided by a partition and provided with two outlets, the one to the right being connected with the clear storage tank and the other with the waste. The drum has a chamber which, when filled with water, causes it to rotate, so as to place the main outlet over the clean water discharge pipe. This chamber is situated under a small orifice in the upper casing, so that a small proportion of the water entering the machine shall pass into the chamber, and so in time by its weight throw over the drum. It is then held in position by this small stream filling a tank at the top left-hand portion of the drum, from which it is conducted by a pipe at the back to the main outlet, while at the same time the contents of the drum chamber are delivered into the waste discharge by a small automatic syphon. When the rain ceases this small tank soon empties, so letting the drum swing back into the position for dealing with the impure water at the commencement of the next shower. Doors are provided for removing the various strainers, and the central drum can be withdrawn for cleaning. A horizontal arrangement of the apparatus is also made, for fitting in situations where the height is restricted.

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630. Model of filter press. Lent by Messrs. S. H. Johnson and Co., Ltd., 1906. M.3451.

The slowness of gravitational filtration caused the construction of pressure filters at an early date, *e.g.*, Bramah in 1797 patented one for the brewing industry, which had a single cell supporting filtering material through which the liquid was forced upward by a pump.

The filter press, exposing a very large area of filtering surface in a small space by using a number of cells in parallel, was introduced in 1852 by Messrs. W. Needham and J. Kite. The cells were built up of grooved boards, covered with cloth and distance frames, alternately, the whole being clamped together by tie-bolts. The cells were piled one on the other and there was a separate pipe joint for each distance frame, so that the apparatus was slow in operation; the arrangement of the cells side by side was soon afterwards adopted.

In the modern form of press the cells rest upon and slide along two side bearers; passages for the inflow of the liquid are contrived within the margins of the plates and all joints are made simultaneously by tightening a single screw; the construction is entirely in metal. These improvements are mainly due to M. V. Danek, in France, and to Mr. S. H. Johnson, in this country, between 1862 and 1876. The improvements since effected have been in detail to adapt the press to such different substances as oil, sugar, sewage sludge, gold ore slimes, etc.

The model illustrates the general principle of the press, but has only a few of the cells of which an actual press would be made up. The

cells are of the flush plate type with the pyramidal drainage surface patented in 1890 by Mr. Johnson, *i.e.*, they are covered with studs or bosses which, while equally efficient as fine ribs in giving support to the filter cloth or paper, give a greater area for the filtrate. Holes are cut in the paper or cloth to match the passages through the margin of the frames. The depth of the cell, and consequently the thickness of the cake produced, is determined by the distance frame. A hand pump, with an air vessel and pressure gauge, is provided for forcing in the liquid. After the cells are filled, the precipitate may be washed free from the filtrate by forcing liquid through the same or a similar passage.

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631. Early water pipes. Presented by the New River Co., 1902. M.3249.

These are specimens of the wooden pipes used in London before the adoption of iron water mains. Probably the London distribution had been by leaden mains, and when this system was destroyed by the great fire in 1666, the adoption of wood was decided upon on account of the distrust generally felt concerning water that had long been in contact with lead. Wooden pipes had been in use for many years when an improvement was made in the methods of connecting them. It consisted of introducing an iron band driven into the timber around the socket end, to prevent the bursting of this part through the expansion of the wood, upon which action the tightness of the joint depended.

The wood generally employed was elm, and owing to the inability of such timber to resist considerable pressure the diameter of the internal hole was usually limited to 6 in. or 7 in., though in favourable situations bores of 10 in. or 12 in. were sometimes adopted. The usual practice where extra carrying capacity was required was to increase the number of 6-in. pipes, so much so that in one street in 1810 there were nine of these lines of pipe laid side by side. The leakage was serious, being estimated at about 25 per cent. of the total quantity of water admitted; but it was not till 1820 that the substitution of iron mains was generally carried out. The boring of the holes was performed either by augers or by a method patented in 1796, in which a hollow iron tube with a circular cutter at the end removed the centre of the trunk in one piece, which could be used for a smaller pipe or other purpose, the tool being an anticipation of the trepanning tool sometimes used in boring guns.

In America and other localities where timber is plentiful, pipes of elm, red gum, or pitch pine are still made of considerable dimensions, but the method of construction consists in building the pipes up continuously from staves or planks with their joints machined, the circumferential strength being supplied by external iron hoops.

632. Water taps. Presented by Mons. E. Bourdon, 1876. M.1841.

These represent two forms of valve patented by Mons. Bourdon in 1867, in which the passage is controlled by a rolling curtain, or flap, of leather. The valve is constructed as a cylindrical casing, which may have a glass front, and the water enters directly into the casing

by one orifice and leaves it by a lower orifice provided internally with a circular seating of large radius pierced with a number of small outlet orifices. To one extremity of the seating the end of a leather flap is secured, while the other end of the flap is attached to an arm which may be turned by an external handle, by which means the number of holes covered by the flap can be varied, and thus the discharge be controlled.

633. Asbestos-packed cocks. Lent by Messrs. J. Dewrance and Co., 1880. M.2507

This cock, of which three forms are shown, was patented in 1877 by Mr. J. Dewrance, but the special feature is the same in each, and consists in the introduction of fibrous asbestos packing, to secure tightness. The plug is of the usual construction, but has comparatively little taper, and the key is fitted to the smaller end. The body of the valve is formed with four longitudinal recesses and a circular recess at each end, all to be packed with asbestos. Above and below the plug are screwed covers, which act as glands for tightening up the asbestos packing as required. It is stated that such fittings permanently retain their tightness, and are less liable to set fast than those of the simple metal on metal construction.

634. Water tap. Lent by the Palatine Engineering Co., 1891. M.2410.

In this tap, patented by Lord Kelvin in 1889 and 1891, the valve is screwed down on its flat seating, but when in contact a gradually increasing pressure is applied by means of the internal spring, so that the valve rotates and cleans its seat before quite closing. There is no packing to prevent upward overflow while open, but any water escaping past the screw is drawn off by a tube inside the spout, the flow of water inducing the current.

635. Water tap. Presented by R. E. Prosser, Esq., 1901. M.3192.

This arrangement of bib tap was patented in 1898 by Mr. G. O. H. Klopp. In it the flow of water is controlled by a hollow ball of vulcanite or metal which is forced upward, by the water pressure, against a ring seating of rubber, while a screwed vertical spindle enables the operator to push the ball downward from its seat to any desired extent. No gland is used, as the leakage from the spindle while the tap is open is conducted into the outlet. The rubber washer can be replaced under pressure, as, while this is being done, the ball beds on a metal seating.

636. Vented plug cock. Presented by F. Ward, Esq., 1906. M.3455.

This cock is designed to draw liquid from a sealed vessel such as a cask. The stoppage of flow that occurs when the pressure inside becomes the same or less than that outside is usually overcome by admitting air by means of a vent peg ; in the cock shown this function is automatically performed in the act of turning on the cock itself,

Cocks of this kind having an external pipe to the vent were designed as early as 1816; the one shown was patented by Mr. Ward in 1904. A vent pipe reaching from the nose of the plug to a chamber within it communicates with a similar pipe extending to the spigot inside the cask when the plug is turned full open. When the liquid in the receptacle to be filled reaches the level of the nose of the plug no more air can enter and flow ceases. A vent in the casing admits air to the plug when turned off so as to empty it.

637. Valves for water-closets. Contributed by P. J Davies, Esq., 1873. M.1287.

These valves, patented in 1872 by Mr. P. J. Davies, are for regulating the flow of water in water-closets, and preventing waste by releasing the valve by means of a cataract, and allowing it to close when a sufficient quantity of water has passed. The following description of one form will explain the principle: a closed metal cylinder, in which works a piston, is fixed on the top of a leather-seated valve; the pull of the handle is communicated by a wire to the piston rod, and the water contained in the cylinder can only leak slowly past the piston; the cylinder and valve are lifted with the piston, but gradually drop and shut off the water, even though the handle may be held up.

638. Model of water-closet mechanism. Presented by T. Penn, Esq., 1873. M.1305.

This is a mechanism, patented in 1870 and 1872 by Mr. T. Penn, for application to water-closets on the old pan system; its object is to release the ordinary valve lever so as to prevent waste of water. A vertical sliding bar, with its attachment, is lifted by the pull of the handle; a quadrant lever lifts the ordinary valve lever, which opens the valve. The quadrant lever is held in its normal position by a balance-weight and by a cataract; it will therefore yield slowly and release the valve lever if the handle should be held up for any length of time.

639. Leakage detector. Presented by H. H. Sporton, Esq., 1901. M.3167.

This is an instrument for rendering audible the slight sound made by water flowing in a pipe, so that if the noise continues, after certain valves are closed, the existence of a leak is indicated. It was originally invented in 1881 by Dr. J. Graham Bell, and by its use in Cincinnati in the following year, it was believed that the waste of water was halved. It consists of a circular box of hard wood, provided with a central orifice resembling that of a telephone, and containing a thin disc of metal, free at its circumference, but secured at its centre to a wooden rod 3·5 ft. long, extending from the back of the box. When the ear is placed at the orifice and the distant end of the rod is in contact with a water pipe, the sound from the pipe is transmitted by the rod to the disc, which causes the whole of the air in the box to vibrate, so that the sound is heard considerably magnified by an ear applied at the orifice. Mr. Sporton found that by dishing the disc and cutting it to a polygonal outline, as shown, the action was intensified.

FIRE ENGINES, ESCAPES, ETC.

Fire Engines.—Provision for extinguishing a conflagration was made by the ancients, who provided and used what are now known as fire buckets, while the Romans had leather water bags with pipes attached from which jets were projected by pressing the bags. Hero of Alexandria about 150 B.C., described "the syphon used in conflagrations"; it was a double cylinder manual fire engine delivering an intermittent jet through a branch pipe carried by a swivel joint. Little further advance was made during the following 1,800 years; but in 1670 Van der Heide introduced the use of leather hose for the suction and delivery pipes; air vessels to give continuous jets were added at about the same time. In England till early in the 18th century the only form of engine was the fire-squirt which held three or four quarts of water; in 1730, however, Newsham introduced the typical parish fire engine, and the first engine in America was also of his make. The steam fire engine was invented by Braithwaite in 1829 and first used on a fire at the Argyle Rooms in London in the following year, but the general adoption of such engines only commenced in 1860, at which period also the floating engines on the Thames were introduced.

Sprinklers.—These arrangements, for delivering water sprays at fixed points in buildings, aim at the extinction of a fire in its early stages. The jets are all connected with the water supply, or with an elevated tank, and can be turned on in groups by hand, or else are started automatically, when the temperature in any portion of the protected area rises abnormally. Some arrangements depend on a thread being burnt through, but the usual plan relies upon the release of a valve held in place by levers connected by a solder fusing at about 160 deg. F.

Alarms.—Many appliances have been introduced which should give warning upon the outbreak of a fire in any part of a building. One, by Sir W. Congreve, relied on the expansion of alcohol to release a weight-driven train which rang a bell; in another an electric contact was made by a compound bar which curved when heated, but in the latest the expansion of mercury makes a contact in a medium that protects the surfaces. The electric system enables the alarm bells to be at any distance from the fire detectors, and in sprinkler systems there are similar bells which ring when any sprinkler comes into action.

Fire Escapes.—Numerous devices have been introduced for rescuing persons who may be in a burning building. Some of the earliest consisted of a slung seat, attached to a rope by which a person lowered himself from a window, just as is still provided in wooden houses in Norway. In 1809 telescopic ladders in three lengths were introduced to facilitate escape, while in 1813 a light rope ladder with iron rounds was proposed. In 1816 a long pole, down which a sliding basket could descend, was tried, and in 1820 a large canvas tube extending from the window to the ground was first used as an escape. About 1835 Mr. Merryweather constructed a series

of ladders which would fit end to end till the requisite length was obtained, and about 1840 Mr. Wivell, by combining the portable ladder with the canvas shoot, introduced the now general form of escape.

640. Old fire squirt. Presented by the Vestry of St. Dionis, Backchurch, 1877. M.1831.

This is an old squirt or syringe used about 1750–70 in the City of London for extinguishing fires. It is made of brass, and has two handles cast on, for slinging it during transport and for holding it when in use, probably as indicated in the accompanying woodcut, which illustrates fire extinguishing at three different periods. The bore of the squirt is 2·5 in. diam., and of the nozzle ·5 in.

641. Japanese fire-pump. Presented by H. H. Howell, Esq., 1861. M.1832.

This form of single-acting hand-pump was in general use in Japan in 1860 for extinguishing fire. The lower end was placed in a bucket of water, and the inclination of the intermittent jet produced on working the handle was adjustable by a swivelling joint in the delivery pipe.

The barrel is formed by boring a hole 1·2 in. diam. through a rectangular post 3 ft. long, in which another hole is bored parallel with it up to the junction for the delivery pipe. The lower end of the barrel is fitted with a foot valve in the form of a sheet metal clack, loosely pinned to a wooden seating, and a similar fitting secured in the side passage forms a delivery valve. The piston is formed of cloth tied to a rod resembling a plunger, provided with a cross handle. The jet delivered is ·2 in. diam.

642. Newsham's fire engine. Presented by the Town Council of Dartmouth, 1875. Plate XI., No. 1. M.1362.

Richard Newsham, of London, in 1721–5, patented "a new water engine for the quenching and extinguishing fires," and the example shown is of his make. It has two single-acting pump barrels 4·5 in. diam., 8·5 in. stroke, and a tall air vessel to secure a continuous discharge. The pumps are placed in a tank which forms the frame of the machine, and the water to be pumped was brought in buckets and emptied into the tank, but the suction inlet to the pumps is provided with a two-way cock, by which the pumps can be arranged to draw either from the tank or a length of suction hose. Leather hose for "conveying water to and from fire and other engines" was patented in 1676, and Newsham used it, connecting his suction hose at the base and the delivery at the top of the casing enclosing the air vessel. The pumps were worked by men at the long cross handles, as in the modern "manuals," but in addition two treadle boards were provided near the centre of the machine, upon which several more men stood and assisted the pumping by throwing their weight on the descending treadle.

These engines were generally adopted and fully appreciated, as is shown by the following extract from a circular of the period :—" Richard Newsham, of Cloth Fair, London, Engineer, makes the most useful,

substantial, and convenient engines for quenching fires, which carries continual streams with great force. He hath play[d] several of them before His Majesty " (*i.e.*, George I.), " and the nobility at St. James's, with so general an approbation that the largest was at the same time ordered for the use of that Royal Palace." It was remarked of Newsham by a writer in the *London Magazine* for 1752, that in his engines he gave " a nobler present to his country than if he had added provinces to Great Britain." Desaguliers considered that no part of the engines could be altered for the better, and the general feeling was greatly in favour of them, they being purchased by the various parishes throughout the kingdom, and Newsham received numerous orders for them from all parts of the world.

At the front of the engine, but protected by a door and a sheet of horn, will be found quaint directions for keeping the engine in order.

643. Drawing of Braithwaite and Ericsson's fire engine. (Scale 1 : 12.) Received 1869. M.2772.

This represents the first steam fire engine, which was patented in London by Messrs. John Braithwaite and John Ericsson in 1829–30. It consisted of a boiler and two direct-acting steam pumps mounted on wheels for horse traction, and weighed 2·25 tons complete.

The boiler was similar to that of the " Novelty " locomotive (*see* No. 13), but smaller, and had a vertical cylindrical water-jacketed fire box with a door at the top to feed in the fuel and a closed ash-pit below into which air was pumped by a mechanical bellows. From the vertical shell extended a horizontal barrel containing a single flue which traversed its length three times, the waste gases issuing by a funnel near the driver's seat. The pumping apparatus was horizontal with two steam cylinders 7 in. diam., and two pumps 6·5 in. diam. ; they made 35 to 45 strokes per min. The slide valves worked by rocking levers actuated by the crossheads, as were also the blowing apparatus and feed pump, but these latter had also hand levers. The feed water was heated by the exhaust steam in passing through a coil. The quantity of water thrown was 30 to 40 tons per hour to a height of 90 ft. through a 1·25 in. diam. nozzle. Although the engine was worked gratuitously at several fires in London with great success, it met with determined opposition. Three or four similar engines were, however, built for Liverpool and abroad, but it was not till 1852 that steam fire engines were permanently adopted in London.

644. Drawing of early steam fire engine. (Scale 1 : 12.) Received 1869. M.2773.

This shows an engine constructed by Mr. P. R. Hodge at New York in 1840, which is stated to have been the first steam fire engine built in America.

It resembled a four-wheeled road locomotive, and was self-propelled ; the boiler was of the locomotive type, with Bury's fire-box, and there were two outside horizontal cylinders 9·5 in. diam. by 14 in. stroke actuating the wrought iron driving wheels. When the scene of operations was reached, one end of the engine was raised till the driving wheels were off the ground, when they acted as fly-wheels. The pumps were placed tandem with the cylinders, and were directly driven by the piston-rods produced backward. The delivery took place through

from one to four jets, and the quantity of water thrown is stated to have been 290 tons per hour, to a height of 166 ft., when using a 2·15 in. diam. nozzle and drawing from a depth of 12 ft.

645. Model of a manual fire engine. (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1894. M.2569.

This sectional model shows the construction of a large modern manual fire engine such as was used by the London Metropolitan Fire Brigade. The body is of timber and carried on large road wheels, with a fore-locking carriage. It is borne on springs throughout, and provided with a powerful hand brake, and generally arranged for rapid hauling by two horses. The roof of the carriage is hinged so as to give access to the interior, in which the hose and other accessories are conveyed, while the roof also serves as a seat for the firemen, and is furnished with two cross hand-rails for enabling them to retain a firm hold during rapid transit. The tops of the long side boxes, which contain the two lengths of suction hose, also serve as footboards.

The pumping machinery consists of two vertical single-acting pumps packed with cup leathers, and arranged on a base that contains the valve boxes. The valves are simple metal clacks, and are readily accessible by two covers, which are held down by set screws. The suction can be taken in through suction hose, or, when working close to the main, the hydrant delivers directly into the chamber containing the pumps, this arrangement being the same as in Newsham's fire engine of 1725 (*see* No. 642). The delivery passes out through a branched pipe having a union on each side of the engine, and on this pipe is a large copper air vessel to secure a uniform discharge. The pump pistons are steadied by overhead guides, and are driven by links from a horizontal shaft running the length of the machine. The ends of this shaft are fitted with levers, which are connected outside the framing by the two long hand-levers with their extension handles, by which the men do the pumping.

The pumps are 6 in. diam. and 8 in. stroke, and the engine is intended to be worked by 22 men, who will pump 100 gals. of water per min. in a continuous jet to a height of 120 ft.

646. Model of a steam fire engine (working). (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1891. Plate XI., No. 2. M.2404.

This model and the adjacent sectional drawing very accurately show the construction of a modern steam fire engine. The machine is carried by large wheels on mail-coach axles, with a fore-locking carriage, and is generally arranged for rapid travelling, two horses being employed. The delivery hose is stored in a central box, which also contains a tank for the boiler feed water. The two lengths of heavy suction hose are carried, one on each side, beneath the firemen's footboard, and a coal bunker under the fore-carriage holds a supply of fuel conveniently near the furnace door. The box seat is utilised as a tool store, and two short branch pipes with nozzles are carried, one on each side of the box, and two long ones over the hose-box. The pole terminates in a special form of crap, by which a horse that has fallen can be quickly released, and the hind wheels have a powerful lever brake.

The pumping machinery consists of a vertical steam cylinder 7·5 in,

diam., 7 in. stroke, and a double-acting bucket and plunger pump with an 8 in. bucket and a 6 in. plunger. The piston is directly connected with the plunger by two piston-rods, which permit the horizontal crank-shaft to be placed in the centre line of the engine, a return connecting rod from the interior of the plunger connecting the reciprocating parts with the crank-pin. A full stroke is thus secured, and a fly-wheel introduced which carries the engine over its dead centres. An over-hanging eccentric works the slide valve, and also a feed pump attached below in line with the valve-rod. The suction box of the pump is directly below the barrel, and the delivery takes place above, two sluice-valves being arranged to direct the water into two lengths of delivery hose. A spring-loaded relief-valve permits the return of water from the delivery box into the suction valve-box if the pressure rises above that which is safe for the hose. A large copper air-vessel is placed on both the suction and delivery boxes, to prevent any concussion in the pipes, and a pressure gauge in front of the boiler registers the pressure in the hose.

Steam at 100 lbs. pressure per sq. in. is supplied by a vertical boiler, internally fired, and having the fire-box crossed by numerous rows of inclined water-tubes, the total heating surface obtained being 56 sq. ft. The boiler shell is in two lengths, bolted together, to render the fire-box accessible for cleaning and repairs. The shell and fire-box expand towards the base, so increasing the grate area up to 4·5 sq. ft., and owing to the exhaust from the cylinder being sent through a blast pipe in the funnel a very sharp draught is obtained. The boiler is provided with two spring-loaded lever safety-valves, an injector, steam whistle, and a jet into the funnel for urging a poor fire, besides the other usual fittings.

The engine indicates 30 H.P., delivers 350 gals. per min., and weighs rather under 1·5 tons. With a 1·125 in. nozzle, the jet reaches a height of 160 ft. Steam is raised to the full pressure of 100 lbs. per sq. in. in six minutes from the time of lighting the fire.

This model is in all respects a complete working machine, even to the pressure gauges and injector. The boiler is of copper with 70 cross tubes, and was tested to 300 lbs. per sq. in. It burns coal, and has raised steam from cold water in seven minutes. The engine throws a continuous jet ·187 in. diam. to a height of 65 ft., when running at 360 revs. per min.

647. Model (working) and drawing of a double-cylinder steam fire engine. (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1892. M.2451.

This model and the adjacent sectional drawing show the construction of a large modern steam fire engine with horizontal cylinders such as is used on docks or other large areas of warehouse property. In many respects the details resemble those of the smaller model, but the delivery hose is stored in the front box and two coal bunkers on the footplate hold a supply of fuel.

The pumping machinery consists of two horizontal steam cylinders 7 in. diam., 7 in. stroke, and two double-acting horizontal piston pumps 5 in. diam. The steam pistons are directly connected with the water pistons by common piston-rods. The crank-shaft is above the centre line of the cylinders and pumps, and is driven by a return connecting rod from a crosshead, which slides in guides fixed above the pumps and

is carried forward and downward to the piston-rod. The suction and delivery valve chambers are directly below the pump barrels, and by removing a few bolts the valves are easily accessible. The delivery takes place above, two double sluice valves being arranged to direct the water into from one to four lengths of delivery hose. A large copper air vessel is placed on top of the delivery chamber, and a small one on the suction chamber to give a steady flow in the pipes, and a pressure gauge on the inside of the box above the pumps indicates the pressure in the hose.

Steam at a pressure of 100 lbs. per sq. in. is supplied by a vertical boiler, very similar to that in the smaller engine, but having 76 sq. ft. of heating surface and 6 sq. ft. of grate area. The engine indicates 45 H.P., delivers 450 gals. per min., and weighs about 1·75 tons. With a 1·5 in. nozzle the jet reaches a height of 190 ft. Steam is raised to the full working pressure in ten minutes from the time of lighting the fire.

The model is in all respects a working machine, and the boiler, which is of copper, has 80 cross tubes, and has been tested to 300 lbs. per sq. in. It burns coal, and has raised steam from cold water in ten minutes. The engine throws a continuous jet ·2 in. diam. to a height of 75 ft. when running at 280 revs. per min.

648. The Grinnell automatic sprinkler. Lent by Messrs. Dowson, Taylor and Co., 1890. M.2338.

This sprinkler, patented by Mr. F. Grinnell in 1881–90, consists of a thin German silver diaphragm, in the centre of which is an opening about ·5 in. diam., through which the water is discharged. The valve which closes this opening is a hemispherical plug of glass and is held up to its seat by a strut composed of three pieces of German silver. These are so fashioned and joined by fusible solder that, on being heated above 155 deg. F., the solder melts and they spring apart, allowing the water pressure above to push away the glass valve. The stream of water which then issues from the central hole impinges on a toothed deflector below, by which it is sprayed outwards over a considerable area.

Lines of small pipes are carried through the buildings close to the ceilings and connected with the water main or to an elevated tank so as to secure sufficient water pressure. As soon as a fire occurs the hot air rises to the ceiling, where it soon heats the sprinklers sufficiently to melt the fusible solder and so liberate the valves.

There is also an automatic alarm gong which is struck by a rotating hammer, driven by the water directly a sprinkler comes into action.

The sprinklers each protect about 100 sq. ft., and are arranged from 8 to 12 ft. apart. An earlier form of Grinnell sprinkler is also shown with a metal valve and a releasing lever in place of the strut.

649. Fire alarm. Presented by Pearson's Automatic Fire Indicator Co., 1896. M.2943.

This is an arrangement, patented by Mr. G. L. Pearson in 1884, by which an electric bell is rung when the temperature at any particular position in a building rises above a certain fixed degree; it is also adapted for indicating dangerous conditions arising in chemical manufactures.

The apparatus consists of a number of thermometers distributed over the rooms that are to be protected, connected in parallel by two insulated wires terminating in a dry battery, a call-bell, and an indicator board. Each thermometer has fused into its tube, at a height corresponding with the danger temperature, two platinum wires, so that when the mercury rises sufficiently it places them in electrical contact; these platinum wires are connected with the bell circuit. When the building is large there are several circuits, each having a separate signal on the indicator board, which then shows in which circuit the contact that is ringing the bell has been made. To prevent the destruction of the platinum and mercury contacts by sparking, the upper portion of the thermometer contains a purified liquid hydrocarbon. To ensure that the main circuits and bell are in working order, independent test wires are laid by which each circuit can be tried by pressing a button in the indicator room.

650. Models of early fire escapes. (Scale 1 : 6.) Received 1899. Drawings from Woodcroft Bequest, 1903. M.3057.

Although the formation of a society for the protection of life from fire had been advocated by Mr. J. Hudson in 1828, the first effective organisation for the purpose was that founded in 1836 as "The Fire Association of the South-Western District of St. Pancras." In the same year also the "Royal Society for the Protection of Life from Fire" was established for the purpose of providing fire escapes throughout the whole of London.

Previously, fire-ladders were kept at certain spots by the various parishes, but the inadequate nature of the appliances and the lack of organisation caused the loss of life by fire to be so serious that some improvements were generally demanded. Various portable arrangements for facilitating escape from burning buildings were designed by different inventors; but to Mr. Abraham Wivell, an artist, appears to be due the introduction of the most important improvements in fire-escapes, and these are embodied in the models shown, which were used by him about 1836, when lecturing upon this subject. He also advocated the provision of fire-escape stations throughout the London district, as indicated by him on the accompanying map, with the result that by 1865 eighty-five of these stations had been established.

One of the three models shown bears the Royal Society's name, and represents a very complete arrangement. It consists of a main ladder mounted upon a spring carriage, with two large wheels, and provided with a lower framework by which it can be handled and elevated. The ladder is of such length as to reach to the windows of the second floor of a dwelling house, while hinged to the top of it is a swinging ladder which, by means of ropes from levers projecting from it, can be swung upward as an extension that will reach to the third floor. There are also two short ladders, one of which can be attached to the folding ladder when a greater height is required. Beneath the main ladder is a canvas trough, or shoot, down which a person can be passed, and at the upper end of this ladder are rollers to facilitate its elevation against a wall.

In a second model, the upper portion of the ladder slides in roller guides, and is elevated by ropes passing over the terminal pulleys. At the head there is a pulley block for use when lowering persons by a rope.

The third model consists simply of two ladders, hinged together and capable of being locked in the extended position by rectangular collars when the full length is required.

Several original drawings by Mr. Wivell show the ladders as actually used.

LAND TRANSPORT.—I.

Common Roads, Carts, Carriages, and Cycles.

Common Roads.—The Romans appear to have been the first to construct roads systematically, and their system was to make them as direct as possible without regard to gradient. As late as the 16th century the Roman roads were the only ones in England, and even these were so neglected that travelling was only possible on foot or on horse-back. Stage wagons and coaches gradually led to an improvement, while between 1775 and 1800 Macadam and Telford effected changes that brought the leading roads into a state which assisted in a great development of the stage coach service. The introduction of railways checked further progress in this direction for many years, so that but few important works were undertaken, but more recently the high roads have again received attention and their general surface has been greatly improved, largely owing to the extensive use of steam road rollers which were first adopted in 1865.

The wear of roads is approximately accounted for as follows: Atmospheric influences, 20 per cent.; wheels, 30 per cent.; horses' hoofs, 50 per cent.; so that the great cost of maintenance can still be reduced if, by levelling and keeping the surface in good repair, the number of animals employed is diminished.

Carts and Carriages.—The earliest form of wheel, after rollers, was solid without spokes, as is still general in the East; spokes and tires were subsequently added, but the use of springs was discovered much later, probably because the reduction they cause in the resistance is not noticeable unless the roads are tolerably good.

Stage wagons which moved at a speed of four miles per hour were in use in England about 1650, while by 1750 stage coaches were regularly at work, and these continued to improve till 1836, when the average speed was about eight miles per hour and the maximum eleven; the introduction of railways then caused their rapid decline.

On a level road the resistance of a wagon without springs is about 44 lbs. per ton, while with springs it is but 35 lbs. The resistance of an omnibus was found to be 100 lbs. per ton, on newly-laid macadam; 45 lbs. on good macadam; and 30 lbs. on asphalt or granite at the speed of 3·5 miles per hour; on a tramway, however, the resistance is about 25 lbs. per ton, and on a railway only 8 lbs. at this speed.

Cycles.—Although cycling has not had any very extensive practical application, beyond its use as a means of promoting healthy exercise,

there is every indication that it is becoming a most important means of transport for short distances.

The earliest form of cycle was the "hobby or dandy-horse," introduced about 1815, which was essentially a bicycle without pedals, the rider propelling the machine by striking backwards upon the ground with his right and left foot alternately, while maintaining the balance by steering. The arrangement, however, did not possess sufficient merit to overcome the ridicule that it aroused and had almost become obsolete when, about 1840, it was developed into a rear-driven treadle bicycle, by Kirkpatrick Macmillan, a blacksmith of Courthill, in Dumfriesshire. Although many of these bicycles were made, the machine did not become popular, and for some years was neglected while tricycles or "velocipedes," some of which had a front driving wheel, were introduced. In 1866 Pierre Lallement, a Frenchman, fitted cranks to the front wheel of a bicycle and this machine, when introduced into England in the following year, became the first popular bicycle; it was known as the "bone-shaker," and had a front wheel 3 or 4 ft. in diam., and a back one 2·5 to 3 ft. In 1868 Mr. E. A. Cowper patented a wire-spoked suspension wheel, and in 1870 Mr. J. K. Starley patented an arrangement of tangented spokes, while at about the same time rubber tires were added. To increase the speed attainable the diameter of the front or driving wheel was gradually enlarged to more than 60 ins., and in this way was evolved the high and rather dangerous machine known as the "ordinary," which was for many years the accepted form of bicycle. Several arrangements of link work and gearing were introduced, however, with the object of reducing the liability of the machine to capsize on meeting any exceptional obstruction; but, in 1879 Mr. H. J. Lawson constructed a rear-driven geared bicycle, which in 1885 was brought to the present "safety" form by Mr. Starley, who commercially introduced it. The latest great step in the evolution of high-speed road vehicles was made in Ireland in 1888 by Mr. J. B. Dunlop when he introduced the pneumatic tire.

The almost universal employment of the free-wheel clutch and the increasing use of variable speed gears are more recent developments.

Almost every improvement in bicycles has been equally suitable for tricycles, the main difference being the necessity in the latter for a differential gear for turning curves; this difficulty appears to have been permanently solved at the outset, however, by Richard Roberts, who in 1832 patented the application of the three-bevel or spur-wheel "Jack-in-the-box" for this purpose.

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651. Model of Chinese wheelbarrow. (Scale 1 : 6.) Presented by R. Swinhoe, Esq., 1870. M.1712.

This form of wheelbarrow, which has been in use from remote times in China, has advantages over the European arrangement in that it accommodates a much larger wheel, thereby reducing the rolling resistance, and in having the wheel almost directly under the load, thus

throwing but very little weight on the user's arms; it requires the load to be in two portions of nearly equal weight and is not capable of directly carrying or discharging loose material.

The shafts are framed together into an open platform, upon which is built a central structure covering the wheel and also affording facilities for securing the objects to be carried. The joints are made by mortising, but some of the parts are stayed by cords which are tightened by a twisting stick.

In the print below is shown the method of using these barrows for material, but when employed for the conveyance of passengers one person sits on each side, so that they are back-to-back.

652. Models of Burmese carts. (Scales 1 : 6 and 1 : 12.) Contributed by J. Coryton, Esq., 1873. M.1315.

This form of two-wheeled bullock cart is common in Burmah and Bengal, and is a survival of a primitive type of wheeled vehicle. It has solid disc wheels, which are, however, provided with long wooden bushes running on a fixed axle-tree; the oxen are tied to a yoke bearing against their humps and lashed to an ornamental pole, which is forked at the inner end for attachment to the axle and to the body framing. The smaller model is that of a pleasure vehicle, and has modern spoked wheels and an iron axle.

653. Model of tipping wagon. (Scale 1 : 8.) Presented by the Commissioners of Patents, 1857. M.107.

This represents a four-wheeled wagon brought out by Mr. R. Stratton in 1841, and is so arranged as to discharge readily its contents by tipping backward. The hind axle is deeply cranked forward so as to clear the body of the waggon when the latter is tilted. The wagon body is pivoted a little behind the centre of gravity, and when in the horizontal position is locked by a lever in the front.

654. The original brougham. Lent by the Worshipful Company of Coachmakers, 1895. M.2732.

This carriage is stated to have been built in 1838, under the personal direction of Lord Chancellor Brougham, by Messrs. Robinson and Cook, of Mount Street. As the vehicle then in general use by the wealthy was the ponderous coach, the appearance of this small, closed, one-horsed carriage created a great sensation, and led to a complete change in carriage design both here and on the Continent.

It has been several times repaired, and the steps are of later construction, while as originally finished the colour was light olive green, picked out with black, and edged with yellow, but the lining was of blue cloth and ribbed silk, probably as at present. The surfaces of the body appear now very flat and unrelieved, but the more noticeable peculiarities are the projecting case and the guard board behind. Such a case was at the time provided on all coaches, and was originally intended for holding swords, which were thus accessible from inside. The guard board, which is 1 in. thick, and carried by detachable brackets, was known as an "opera board," and was placed in position when the carriage was likely to be used in crowded traffic; the then defective police control and other causes rendered "poling" by the following carriage a serious and imminent danger.

655. Model of brougham. (Scale 1 : 6.) Made by James Reid, Esq. Received 1906. M.3433.

This model shows the construction of a pair-horsed double-seated brougham, the materials being left in their natural colours and the upholstery omitted so that the details may be seen. The body is framed in wood and covered with thin panelling, but it is strengthened longitudinally by a vertical steel plate at each side, which follows the lower outline of the body and extends forward to carry the driver's box. The front seat may be tilted up when not in use. The body rests in front on a spring-supported fore-carriage constructed of steel and wood, while at the rear end two projecting bars, firmly secured to the framing, are attached to the springs of the hind axle. The springs are of the modified C form patented by Mr. G. H. Morgan in 1876, with which no perch is necessary. The lower part of each C spring is fastened to the axle and extends beyond it, forming an elbow spring which is coupled to a similar spring above it: this upper spring is bolted to the carriage supports and its other end is suspended from the top of the C spring by a leather link. The vehicle is steered by a pole attached to the fore-carriage, to which the traces are also attached. The wheels have iron tires, and brake blocks are applied to the hind wheels by levers pivoted on the bottom of the body and actuated by a lever at the side of the box.

656. Model of landau. (Scale 1 : 6.) Made by James Reid, Esq. Received 1902. Plate XI., No. 5. M.3250.

In this model, which represents the most general form of pair-horsed private carriage, the materials have been left in their natural colours and the upholstering omitted, so that the details of construction can be more clearly seen.

The under-frame is chiefly built of steel, and is carried upon the hind axle by elliptical springs, while at the front it rests on a fore-carriage supported on similar springs. At each of the four corners of the under-frame projects upward a C spring, from which the carriage body is suspended by adjustable leather straps. The body is framed in wood and covered with thin panelling, but longitudinal strength is given in the middle by a steel plate at each side, set on edge; the attachments for the supporting straps are made of steel bars secured to the body and to these plates, while extending almost to the doorway. The driver's box is carried by a steel framework attached to the body, of which it forms an extension, and side swinging is checked by transverse leather straps, connecting the body with the under-frame.

During inclement weather the carriage can be converted into a closed one by swinging upward the two hoods, which meet at the top and form a continuous closed roof and sides, except at the doorways, which spaces may then be completely closed by glass windows that can be pulled upward from recesses containing them in the lower portion of the doors. The work of raising the hoods is facilitated by springs, while when in position they are fixed by a knuckle-joint arrangement that tightens the leather covers.

The vehicle is steered by a pole attached to the fore-carriage, and the pull of the horses is exerted by four traces, also connected with the

fore-carriage. The wheels have iron tires, into which cushion tires of rubber are secured.

In the landau represented there is a brake fitted to the hind wheels, capable of being applied by the driver through a wire rope and a pair of levers carrying brake pads and having their fulcra secured to the under-frame.

657. Reproduction of hobby horse. Presented by H.G. the Duke of Northumberland, K.G., 1904. Plate XI., No. 3. M.3334.

The hobby, or dandy horse, the forerunner of the bicycle, was patented in France by Charles, Baron von Drais, in 1818, and in the same year was introduced into England by Denis Johnson, a coach-maker of Long Acre, who took out a British patent for it, in which he described it as a "Pedestrian Curricle." Its use became a recreation for some time, but called forth much ridicule, which its merits did not enable it to survive.

The machine consists of a wooden bar, or backbone, strengthened by iron and supported by means of light iron work upon two wheels, arranged one behind the other, the front one being mounted on a fork socketed in the front end of the backbone. It was propelled by the rider, who, while astride of the saddle on the backbone, and leaning his elbows on the well-padded support, scuffed backward upon the road with the right and left foot alternately, at the same time maintaining the balance of the machine by steering by means of the handle bar which, as in the modern bicycle, is fixed to an extension of the front fork; the earlier steering arrangement is shown in the prints. A stay-rod linked to the backbone was provided to retain the machine upright when not in use. The speed attained was as much as 10 miles per hour on the level.

The machine shown is an exact reproduction of one preserved at Alnwick Castle, and has equal wheels 29·3 in diam., and a base of 41 in.; it weighs 52 lbs.

658. Engravings of the hobby or dandy horse. Received 1902. M.3251.

The machine represented in these prints is the original form of the bicycle (*see* No. 657).

The machine consists of a bar or backbone supported, by means of light iron work, upon two equal wheels arranged one in front of the other and carrying a seat for the rider in addition to a support for his arms and chest. It was propelled by the rider, who, while seated, leaned forward and scuffed backward upon the ground alternately with each foot, at the same time maintaining the balance and steering the machine by means of a handle connected with the fork carrying the front wheel. The steering fork was pivoted in the front of the backbone, but instead of being continued through it to receive the steering handle, the handle was connected with the fork by a long bent rod brought upward from the front of the fork; in slightly later forms of the hobby horse the steering fork was in this respect constructed as in the modern bicycle.

The upper engraving is modern, having been prepared in 1894, but the lower one was published in 1819, and shows the interior of Johnson's Riding School, where the use of the machine was taught.

One of the riders is represented as "coasting," which was the recognised way of descending hills; when, however, a hill had to be ascended, it appears to have been usual to carry the machine on one shoulder.

A modification of the hobby horse was introduced about 1819 for the use of ladies, and it had the downward curved backbone or drop-frame now general in ladies' bicycles. The weight of a hobby horse was about 50 lbs., and the price was from £8 to £10.

659. Velocipede. Lent by H.M. King Edward VII., 1901. M.3196.

This rear-driven front-steering quadricycle belonged to H.R.H. the late Prince Consort, for whom it was made, probably about 1851, by Mr. J. Ward, a coachbuilder of Leicester Square, W.C. A very similar machine had been constructed about 1819 by the Rev. Edmund Cartwright, and many other forms of "pedomotive carriage," or velocipede, were built at various periods, but after the introduction of the bicycle the more expensive and cumbrous arrangement became of but secondary interest.

The velocipede shown has a frame of solid iron carrying a cushioned seat, the rear axle turns in bearings attached to the frame, while the fore-carriage is connected by a swivel plate and central bolt. The rear axle is bent into two opposite cranks, which are driven by treadles attached to them and suspended by links from the front extension of the frame; the rider's feet are held by straps to clogs adjustably secured to the treadles. The vehicle is steered by a single hand lever connected with the fore-carriage.

The wheels are of wood with iron tires; the front wheels are 34 in. diam., the driving wheels 40 in. diam., the crank radius 7·75 in., but the semi-vertical motion of the clogs is only about 4 in. The total weight of the machine is 115 lbs.

660. Early bicycle. Presented by Killingworth W. Hedges, Esq., 1905. Plate XI. No. 4. M.3140.

This form of bicycle, now known as a "boneshaker," was probably invented in 1865–6 by Mons. Pierre Lallement, and was introduced into this country two years later.

The example shown was made by Mr. Hedges in 1869, and the lamp was fitted the following year. The frame is of solid wrought iron and the wheels of wood with iron tires. It is driven by triangular pedals of wood fitted to cranks on the front wheel, while the rider sits on a saddle mounted on a plate spring supported at one end by the socket head and at the other by struts from the back wheel bearings. Steering is done by a handle bar at the top of the fork, and a brake on the tire of the hind wheel is applied by a cord which can be tightened by rotating the handle bar. Leg rests, which provide supports for the hocks when "coasting," are carried by a forward extension of the backbone, and these, together with the saddle, are fitted with rubber padding.

The machine weighs 68 lbs. The front wheel is 36 in. diam. and the back one 30 in. The crank arms have two pedal holes, giving lengths of 5·75 and [illegible]·5 in. respectively.

661. "Phantom" bicycle. Presented by A. Markham, Esq., per "*Cycling*," 1901. M.3178.

This machine embodies improvements patented in 1869 by Messrs. W. F. Reynolds and J. A. Mays, the most important of which is the substitution of wire spokes, in tension, in place of rigid spokes acting as struts. The suspension wheel constructed with leather straps or cords was, however, patented by Mr. G. F. Bauer in 1802, while the iron-spoked wheel for ordinary vehicles was patented by Theodore Jones in 1826, but the "phantom" wheel was the first application of the type to the bicycle.

The wheel has a wooden rim, with eyes screwed into it, and each spoke starting from one end of the hub is passed through an eye and bent so as to return to the other end. The ends of each double spoke were clamped between flanges, and the requisite tension was given by wedging open the rim, which was butt-jointed, or by spreading the two flanges on the hub. The rim was provided with a solid rubber tire stapled to it. The framing is of iron rods, forming two triangles hinged together at their common base ; each half is controlled by rods from the steering handle, so that the machine is a double-steerer.

The front wheel is 34 in. diam. and the back one 30 in.; the machine weighs 53 lbs.

662. Rudge "Ordinary" bicycle. Presented by Messrs. Rudge-Whitworth, Ltd., per "*Cycling*," 1901. M.3181.

This machine was built in 1884, and represents the then accepted type of directly-driven high machine; it was used by Howell in numerous races, and was exceptionally light, weighing only 21·5 lbs. The large wheel is 58 in. diam., the small one 16·2, and the cranks are 5 in. long.

663. Early "Safety" bicycle. Lent by T. E. Osborne, Esq., 1907. M.3492.

This is a specimen of the rear-driving safety bicycle patented by Messrs. H. J. Lawson and J. Likeman in 1876. The first bicycle, made by Kirkpatrick Macmillan in 1839, was a very similar crank and lever-driven machine.

The machine has a large driving wheel and a smaller steering wheel in front of it, the saddle being placed between them at such a height that the rider's feet could easily touch the ground. The wheels are held in vertical forks connected by a frame consisting of two tubular members. Adjustable cranks on the rear axle are driven by connecting rods from the upper arms of bell crank levers whose lower arms carry the pedals. The wheels have wire spokes and solid rubber tires, and the axles are fitted with roller bearings. The driving wheel is 50 in. diam., and the steering wheel 28 in. The pedals have a mean stroke of 11·5 in. and the machine weighs 66 lbs.

664. Bicyclette. Presented by H. J. Lawson, Esq., per "*Cycling*," 1901. M.3179.

This machine, which was patented by Mr. Lawson in 1879, marks an important step in the evolution of the present rear-driven "safety"

bicycle. The rear wheel is increased and placed further back, so leaving room for what is now called the "crank-bracket," and the power is transmitted from the cranks to the rear wheel by a pitch chain. The saddle is so far back that steering is performed by a handle-bar connected with the front fork by a nearly horizontal link.

The front wheel is 40 in. diam., and the back one 24 in., but it is geared to 40. The weight of the machine is 60 lbs.

665. "Otto" di-cycle. Presented by the Viscountess Sherbrooke, 1901. M.3198.

This form of bicycle was patented in 1879–81 by Mr. E. C. F. Otto, and the example shown, which was regularly used by the late Lord Sherbrooke, was built by the Birmingham Small Arms Co. about 1881. The Otto cycle soon became somewhat popular, as it was considered less dangerous than the ordinary high bicycle, but the subsequent development of the safety bicycle led to its complete abandonment.

The machine has two large road wheels, both loose on a straight axle which supports the saddle and the entire framing, but from the back of the frame projects a bar carrying a small rubber-tired roller, which prevents the frame and rider from swinging too far backward, and also can be used as a trailing brake, although normally it is well clear of the ground. Projecting downward in front of the axle are two telescopic rods which support the bearings of a double throw crank-shaft provided with pedals by which the shaft is rotated. At each end of the crank-shaft is a rubber-sheathed pulley, which, by a steel band fitted with transverse driving ribs, drives a similar pulley attached to its corresponding road wheel; in this way both wheels are driven at uniform speed. On each side of the rider is a steering handle fixed to the axle and connected with the crank-shaft bearing in such a way that either driving band can be slackened so that its road wheel becomes free; these steering handles each contain another handle by which a band brake can be applied to a drum on its road wheel. By these arrangements either road wheel can be driven or checked in a way that enables the machine to be indirectly steered. The driving bands are normally kept at the necessary tension by a spiral spring in each of the telescopic legs.

The driving wheels are 56 in. diam., and are 32 in. apart at their tires, which are of solid rubber; the crank radius is 6 in. and the total weight of the machine is 95 lbs.

666. "Rover" bicycle. Presented by J. K. Starley, Esq., per "*Cycling*," 1901. M.3180.

The "Rover" bicycle, invented by Messrs. Starley and Sutton in 1885, embodied most of the features of the present safety machine, and was the bicycle which practically introduced and rapidly demonstrated the superiority of the safety arrangement. The example shown is the second made, and is that upon which Golder rode in the 100 miles race in 1885. The steering head slopes, as at present, but the forks have no set, and the frame is in no sense triangulated.

The front wheel is 32 in. diam., and the back one 30 in., but geared up to 60 in. The cranks are 6·5 in. long, and the machine weighs 37 lbs.

667. "Kangaroo" bicycle. Lent by T. E. Osborne, Esq., 1907. M.3493.

This is a dwarf front-driving machine patented by Mr. W. Hillman in 1884, and constructed by Messrs. Hillman, Herbert and Cooper about that time. It has a small front wheel driven by cranks placed some distance below its centre and connected with it by chains. The fork is raked and continued downward to support the divided crank axle bearings; there is a chain on each side of the wheel. The centre of the wheel is in front of the fork and the bearings slide along it to adjust the chains. The machine is fitted with ball bearings, a spring saddle, and a spoon brake.

The front wheel is 36 in. diam., but is geared to 54 in. The cranks are 6 in. long and the machine weighs 48 lbs.

668. "Geared facile" bicycle. Lent by T. E. Osborne, Esq., 1907. M.3494.

This machine, made by the Crypto Cycle Co. about 1888, illustrates one of the attempts made to render the front driving bicycle safer. This was accomplished by using a smaller driving wheel geared up by sun and planet wheels, and by raking the front fork and thus placing the mass-centre of the rider further behind the wheel centre.

The crank-axle runs in bearings within the hub and is driven by connecting-rods attached to the middle points of vibrating pedal levers, which are pivoted on forward extensions of the fork. One connecting-rod carries a planet pinion which gears with a sun wheel keyed to the hub. Ball bearings are fitted to both axles. The driving wheel is 40 in. diam., but is geared to 60 in.; the pedals have a stroke of 12 in. and the machine weighs 37 lbs.

669. Humber "Safety" bicycle. Presented by Messrs Rudge-Whitworth Ltd., per "*Cycling*," 1901. M.3182.

This machine, introduced in 1888 by Messrs. Humber and Co., embodies the chief feature of the now general diamond frame which, however, only took its present shape about 1890.

The machine was called a "dwarf roadster," and has the front wheel considerably smaller than the rear or driving wheel, a peculiarity that was soon abandoned for equal wheels or else a slightly larger steering wheel.

670. "Bantam" bicycle. Lent by T. E. Osborne, Esq., 1907. M.3495.

This machine, made by the Crypto Cycle Co. about 1893, represents the only surviving machine of the geared ordinary type. It has a very small front driving wheel which is geared up by means of an epicyclic train, this "Crypto" gearing having been introduced into these machines by Messrs. T. Shaw and A. Sydenham in 1891.

The framing consists of a front fork and a single curved tube with a vertical pillar carrying the saddle. The gearing consists of a sun wheel fixed to the hub, four planet pinions carried by a disc attached to the crank, and an outer internally toothed ring fixed to the fork. Thus for every revolution of the crank the wheel makes 2·75 turns.

The machine is fitted with pneumatic tires and the plunger brake pad is in the form of a brush.

The driving wheel is 24 in. diam., but is geared to 66 in. The rear wheel is 20 in. diam., the cranks are 6·5 in. long and the machine weighs 28 lbs.

671. Ratchet clutch. Presented by A. J. Wilson, Esq., per "*Cycling*," 1901. M.3184.

This is shown as fitted to one of the hubs of a "Devon" front-steering double-driven tricycle. It was patented in 1879 by Mr. F. W. Jones as a means of facilitating passing round curves; the two driving wheels were independently driven from the crank-shaft by chains, and the ratchets allowed the outer wheel to overrun when turning a corner. These clutches, however, converted the driving mechanism into a "free-wheel" arrangement. Each clutch has two opposite pawls, which engage simultaneously.

672. Roller clutch. Presented by the Swift Cycle Co., per "*Cycling*," 1901. M.3183.

This is from the driving axle of a "Cheylesmore" double-driven rear-steering tricycle, built by the Coventry Machinists' Co. about 1881.

The sprocket wheel is loose on the shaft, but within it is a six-sided steel cam keyed to the shaft. Between the cam and the wheel are six short rollers, which jam the two together when going in one direction, but leave them free in the other. This clutch was patented by Messrs. J. White and G. Davies in 1881, but it resembles that used in Otto and Langen's gas engine of 1866 (*see* No. 332).

This arrangement was provided to allow the outer wheel of the tricycle to turn in advance when passing round a curve, but it also gave a "free-wheel" drive. To allow of back pedalling, the sprocket wheel was also fitted with a ratchet-face clutch, which was automatically thrown out of gear by the steering handle.

673. Roller clutch. Presented by Messrs. Humber Limited, per "*Cycling*," 1901. M.3185.

This clutch was made by Mr. Thomas Humber, and appears to have been intended for the front axle of an "Ordinary" bicycle, which would thus be given a free wheel, It resembles the Cheylesmore roller clutch (*see* No. 672), and is of probably about the same date.

674. Early ball bearing for bicycle. Presented by Messrs. Humber Limited, per "*Cycling*," 1901. M.3186.

This shows the construction adopted by Mr. Thomas Humber about 1880 for reducing the friction of the back wheel hub of an "Ordinary" bicycle.

The inner faces of the fork and the outer faces of two collars on the spindle have each cut in them a semi-circular groove, so that steel balls

can be inserted which will carry both the vertical and lateral pressures. The arrangement is adjustable for wear.

Note.—Several examples of cycle driving mechanism will be found in the collection of Kinematic Models on the first floor of the Southern Galleries.

LAND TRANSPORT.—II.

Tram and Railroads, Including their Signalling Appliances.

Permanent Way.—The provision of smooth wheel tracks which should both withstand wear and reduce the power required in haulage was to some extent practised by the Romans, who used stone blocks, but the modern development of the system dates from about 1650, when the laying of longitudinal timbers on the road was commenced in the Newcastle district in connection with the coal industry. Wooden curbs were sometimes added to these timbers. These wooden ways wore irregularly and at first were patched with wood, but in 1767 facing plates of cast iron were substituted at Coalbrookdale, with a marked reduction in the wear and also in the tractive resistance experienced. The wheels used on these wooden railways were described in 1676 as four rowlets fitting the rails; they were probably small wooden wheels or rollers shaped so as to prevent them from running off the rails. In 1734, however, cast iron wheels with a single inner flange were in use near Bath, while similar wheels are recorded at Whitehaven in 1738, and at Newcastle in 1764. In 1776 a cast iron "plate way" was laid at Sheffield; this was of angle section, the raised flange of which prevented the wheels slipping off the narrow track provided. Although this plate way possessed the advantage of allowing the use of ordinary vehicles upon it, it was open to the serious objection that it caused the accumulation of dirt and stones where they are most prejudicial.

The invention of the narrow iron edge rail is due to William Jessop, who, in 1789, constructed a railway in Leicestershire on this system and subsequently introduced it into other localities. His rails were of cast iron in 3 ft. lengths of girder section and with a curved lower flange, so that great strength was secured by the increased depth; the rapid wear of both his rails and wheels, however, soon showed the necessity for a wider bearing surface than he originally allowed. These rails were, moreover, provided with cast iron feet by which they were secured to the sleepers, but it was found that these feet were frequently broken off, thus rendering the rail useless; this defect was ultimately overcome by the introduction of detached feet or "chairs," first used in 1797 in the Newcastle district.

Wrought iron, although expensive, had for many years been used as a wearing face for wooden rails, but it was not until 1805 that it was used as a girder rail, and then it was of rectangular

section. The more economical T-section came into use in 1820, and much ingenuity was subsequently displayed in rolling the lower web to the "fish-belly" outline which, although correct for the 3 ft. cast iron rails, was wrong for resisting the stresses in a continuous rail 12 to 18 ft. long with intermediate supports.

Parallel rails with a lower flange smaller than the head were introduced about 1830, and on the failure of the fish-bellied pattern, were used on the Liverpool and Manchester Railway in 1834. The double-headed rail was introduced by Joseph Locke in 1835, the intention being to reverse it when one head was seriously worn. This system, rendered necessary by the irregular wear of the wrought iron rails, continued in use for about thirty years, although the under surface was injured where it rested on the chairs. The rails were afterwards rolled to the now common bullheaded section. The flat-footed or flanged rail was also introduced about 1830 and is extensively used in America and elsewhere, its great advantage being that it can be fixed directly to the sleepers without the use of chairs. The ends of the early rails were butted or lap-jointed together in special chairs, but in 1847 Mr. W. B. Adams introduced the fish-plate joint, now universal.

The latest great improvement in permanent way is the substitution of steel rails for those of iron, a change that commenced about 1870, and for which the Bessemer process is to be chiefly credited by its having so greatly increased the output and reduced the cost of steel. Wrought iron rails wear down at about twice the rate of steel ones, but owing to the wear of the steel being uniform, while the wrought iron, after a time, frequently becomes laminated so that it splits or bulges irregularly, it has been estimated that a steel rail may last as long as fifteen iron ones. The almost unlimited length that can be obtained in a steel rail is another advantage which it possesses over one of wrought iron; steel rails, frequently weighing 85 lbs. per yard and upwards, are now rolled in lengths of from 33 ft. up to 60 ft.

The sleepers generally used with the early cast iron plate ways were blocks of stone; and in the first public railway lines the same material was used in cuttings and on consolidated ground while wooden sleepers were used on embankments; with the gradual increase in speed the rigidity of the stone blocks and the absence of gauge ties were found to be serious defects, so that transverse wooden sleepers were gradually substituted. Metal sleepers have been repeatedly tried with considerable success, and are used exclusively where the insect life of a locality is destructive to timber; they are also largely used on narrow gauge lines.

Street Tramways.—Although tramways were the origin of our railways, street tramways which combine the features of the early plate way with those of the railway are a much later invention, and were first developed in America. They were introduced into England in 1860, but the early lines were nearly all removed in a few years and the system was practically abandoned in this country till its revival in 1870, since when its growth has been continuous.

As the resistance of a tramcar on the level is generally under 25 lbs. per ton, the loads carried are much greater than with vehicles running on the road surface, but the proportionate increase in the resistance due to inclines and to the inertia at starting is greater, so that for many years mechanical traction has been much more extensively attempted with tramcars than with ordinary vehicles. Engines worked by steam, compressed air, gas, or electric accumulators, have been tried, but of all systems deriving their power from the permanent way, those of the cable and electric wire are alone in extensive use. The cable system, introduced in 1873, gives constant speed and utilises the weight of the cars on the down grades to assist those on the up, but the construction of the central slot rail and the conduit, together with the guide pulleys, are expensive and the renewal of the wire rope is a serious expense. The electric system is cheap in first cost, provided that overhead conducting wires are tolerated, and is that now generally adopted in provincial towns and surburban districts. The electric system, introduced about 1883, with the conductors in a conduit beside one of the rails or in the centre of the track, is one of those by which the overhead wire is avoided, but is more expensive and has only been adopted in large cities.

Signalling Appliances.—Soon after the introduction of railways, signals from fixed posts were found to be necessary for instructing the drivers, and in 1834 the Liverpool and Manchester line adopted a form of signal that has since been extensively used, the signal and lamp being carried on a vertical shaft which could be rotated from below through 90 deg., so presenting two quite different appearances if seen from a straight line. The semaphore arm introduced in 1841 by Sir C. H. Gregory is the signal now almost universal and from its certainty and general application is probably final. The employment of the electric telegraph in working railway traffic was advocated and tried by Sir W. F. Cooke from 1837 to 1844, but it was not till 1851 that Mr. C. F. Walker introduced the present electric bell signalling. By the use of this system a definite distance was insured between the trains upon the same line instead of definite time only, a most important distinction that led to the development of the block system of working. In 1856 Mr. Saxby introduced a method of mechanically connecting the points and the signals at any junction in such a way that the dangerous combination of these two factors was rendered impossible, thus largely reducing the responsibility of the signalman. Many attempts have been made to cause the train in passing to set the signal automatically, closing the line behind it, but occasional failure led to a few accidents that caused automatic signalling to be abandoned for many years; recently, however, considerable advances have been made in this direction by electric apparatus, the failure of which as with other signalling appliances only delays traffic, since the signal under gravity alone remains at danger. The mechanical labour involved in manipulating a large number of signals and points has led to the application of power to this work, water,

compressed air, and electricity having all been considerably used in America and to a certain extent in this country, but such arrangements are only necessary in exceptional situations where the traffic is dense.

PERMANENT WAY.

675. Early plate way. Presented by the Midland Railway Co., 1893, and C. E. Stretton, Esq., 1900. Plate XI., No. 7. M.2539.

These specimens are from the Ticknall tramway—a line 4·25 miles in length connected with the Ashby Canal, Leicestershire. This tramway was authorised in the Ashby Canal Act of 1794, and was constructed in 1799 by Benjamin Outram, following a route indicated on an adjacent ordnance map. It is still occasionally used.

The metals are of cast iron and of the plate section, with a raised flange which was arranged on the inside of the track; the wheels of the trucks were without flanges. The switch shown has a wrought iron tongue, provided with a stem which drops into a hole in the casting, but no mechanical device is provided for moving the tongue. One of the specimens shows the channel section rail used when the line crossed a highway.

676. Toll sheet of the Surrey Iron Railway. Lent by Trovey Blackmore, Esq., 1876. Copy of original plan of line. Contributed by C. T. Davis, Esq., 1900. M.2754.

The plate ways called the Surrey Iron Railway and the Croydon, Merstham and Godstone Iron Railway were the first lines of metals constructed for public use, the earlier tracks having been reserved for the exclusive use of their owners. They both formed portions of a scheme promoted in 1799 for improving the communication between London and Portsmouth by providing a horse tramway approximately parallel with the main road and open to the use of the public upon the payment of certain tolls.

The construction of the first portion—the Surrey Iron Railway—was sanctioned by Parliament in 1801 and, the work being at once commenced, it was finished in July, 1803, while, by 1805, the capital involved in the undertaking had reached £60,000. William Jessop was the engineer and the subscribers were chiefly the owners of mills and other property in the valley of the Wandle. The line commenced at a locked dock on the Thames at Wandsworth and followed up the course of the Wandle, which it twice crossed, to Croydon; there was, moreover, at Mitcham Common, a branch to Hackbridge, and several mills along the route had short connecting lines.

The rails were of cast iron in 38 in. lengths, 4 in. wide on the tread and 1 in. thick, with an arched flange, 3·5 in. high and ·5 in. thick, projecting upward along one edge. These rails proving too weak a heavier section with an extra flange projecting downward from the other edge was adopted when repairing. The ends of adjacent rails were secured together on a stone block sleeper, 15 in. square and 8 in. deep, by a special spike driven into a wooden plug fixed in the block. The road was a double track to a gauge of about 4·7 ft. measured outside

the flanges, which were arranged inside the treads; the maximum gradient was 1 : 120 and the high roads were crossed on the level. intermediate packing being laid in such situations to reduce the obstruction occasioned by the flanges.

The second portion of the line was known as the Croydon, Merstham and Godstone Iron Railway and its construction was authorised in 1803. It was intended to extend this line from Croydon to Reigate and to have a branch to Merstham and Godstone, but, owing to lack of capital, construction was stopped in 1805, when the line had reached Merstham limestone quarries, a distance of 8·75 miles. Starting from the Croydon end of the Surrey Iron Railway the line ran south over a course closely followed by the present Brighton Road; it was carried on an embankment on the west side of the road, then crossed by an arch to the east side and reached Merstham through a cutting. Portions of the embankments and cuttings still remain, as also do three bridges over the cutting near Chipstead, but much of the route is now covered by the high road and the Brighton Railway.

On both lines the traction was done by horses and it was considered that, at 2·5 miles per hour, one horse could draw a total load of 9,000 lbs. and that the resistance was 37 lbs. per ton. The waggons were 8 ft. long, 5 ft. wide and 2 ft. deep; each weighed about 1 ton and carried a load of 3·25 tons. The wheels were of cast iron and flangeless, 32 in. diam. by 1·5 in. face, and revolved on fixed axles 2·375 in. diam.

Neither of the undertakings was, however, financially successful and in 1837 the portion of the line between Croydon and Merstham was purchased by the London and Brighton Railway Co., which in 1846 acquired the remainder, the present line from Croydon to Wimbledon now following part of this route. Both routes are shown on an adjacent ordnance map. Some specimens of the stone sleepers, unearthed at Wandsworth in 1906, are shown near. The views at Wandsworth and Chipstead are taken from the *Engineer*, January, 1900.

677. Cast iron edge rails. Presented by C. Stretton, Esq., 1892. M.2472.

These rails were laid down by William Jessop in 1789 on a line between Nanpanton and the Loughborough Canal at Loughborough, the intention being eventually to form a connection with the Ashby coal field (*see* map). This is believed to have been the first instance of a rail being used on its edge, and therefore marks a great advance upon the earlier plateways.

The rails were cast in 3 ft. lengths of a double flanged section, with a curved lower flange forming what has since been known as a "fish-bellied" rail. The lower flange at one end of a rail spreads out to form a foot, which by a central hole was spiked to a wooden cross sleeper. The top of this foot is so formed that the next length can be socketed into it, the spiked end of each rail securing the otherwise free end of the following rail. These rails are much reduced by wear, but probably weighed about 40 lbs. per yard. They are, however, narrower and generally lighter than later examples of Jessop's make.

678. Early cast iron rails. Presented by Messrs. J. and C. Thompson, 1892. M.2485.

These rails are stated to have been in use during the latter part of the eighteenth century on a mineral line in the north of England and

are an early anticipation of the edge rail. Each rail is in the form of a rectangular bar with an elliptical stiffening rib below, while the ends are thickened and provided with side flanges by which each length was directly secured to the wooden cross sleepers by four iron spikes; the abutting ends are, moreover, made concave and convex, possibly to give continuity round curves. The rails are in 3-ft. lengths, each weighing 35 lbs., and the width of head is 2·25 in.

679. Cast iron edge rails. Presented by H. G. the Duke of Rutland, 1892, and C. E. Stretton, Esq., 1900. Plate XI., No. 8. M.2473.

These six rails, with the point and crossing, formed portions of a line laid from Belvoir Castle to the Grantham Canal in 1793, and still in use. The work was carried out with Jessop rails (*see* No. 677), made at Butterley. These were spiked down to plugs in stone blocks at a gauge of 4 ft. 4·5 in. The switch turns on a pin dropped into a hole in the foot of the stock rail, and is without any mechanical attachment for moving or fixing it. The line and the trucks are clearly shown in the attached photographs, and the route is marked in red on an adjacent ordnance map.

680. Early cast iron edge rails. Presented by Messrs. J. and C. Thompson, 1892. M.2486.

These were in use at the beginning of the nineteenth century and resemble No. 678 except in the method of fixing. Each rail is in the form of a rectangular bar with an elliptical rib below, while the ends are made deeper and widened outward on one side where they are provided with a through hole for a wooden plug or trenail; the ends are also notched to secure alignment. They were carried on stone blocks to which they were secured by trenails 1·4 in. diameter. The rails are in 3-ft. lengths, each weighing 34 lbs., and the width of head is 2·25 in.

681. Plate rails. Presented by Capt. E. A. Blackett, R.N., 1862. M.339.

These cast-iron rails are from the waggon-way at Wylam, upon which the early locomotive "Puffing Billy" (*see* No. 124) worked in hauling coal trucks. The track was originally laid with wooden rails which, in 1808, were displaced by plate rails of the form shown; these remained in use till 1830, when the cast-iron edge rails now retained under the engine were substituted.

This pattern of plate rail is similar to the earlier example No. 675, but is strengthened by the addition of a lower segmental flange, 2·75 in. deep at the middle. The rail is 3·5 in. wide on the tread, and is broadened out to 5 in. at each end where it rested on the sleepers to which it was secured by a spike fitting the notches in the ends of adjacent rails. Each rail weighs 45 lbs. and is a yard in length.

682. Wrought-iron rail (1808). Presented by Messrs. J. and C. Thompson, 1892. M.2487.

This is a specimen of the earliest form of wrought-iron rail, and it was in use on a railway at Tindale Fell in 1808. The rail was simply

a square bar, secured to stone blocks by iron spikes, which were driven through the rail into wooden plugs inserted in holes in the stone. It was originally 1·5 in. square, and in 12-ft. lengths, supported at intervals of 3 ft.; it now weighs 17 lbs. per yard.

683. Blenkinsop rails and driving wheel. Lent by the Institution of Mechanical Engineers, 1890, and Messrs. John Spencer and Sons, 1893. M.2325 and 2529.

The specimens comprise an original rack rail, together with two similar rails, three chairs, and a driving wheel recently cast at the Tyne Iron Works from what are believed to be the original patterns, made when equipping the rack line that connected the collieries of Kenton and Coxlodge with the Tyne, which was laid down in 1813 under the patent of John Blenkinsop, of Leeds. These rack rails enabled light engines to haul heavy trains up gradients which the smooth-wheeled locomotives of Trevithick could not have surmounted. The same arrangement is now generally adopted for mountain railways, except that the rack is now an independent structure midway between the two rails. The Kenton and Coxlodge railway did not remain long in use, owing to the engine tearing up the rails, but the similar line at Leeds (*see* No. 122) worked successfully from 1812 till about 1831.

The original rail is of the cast-iron fish-bellied pattern, but is provided on one side with semi-circular lugs, or teeth, into which the driving spur wheel of the locomotive engaged. The rail is 3·4 ft. long, with seven teeth about 6 in. pitch by 2·25 in. face, and weighs 50 lbs. per yard. Its chairs weigh 12 lbs. each, and are formed with projections to fit under the end teeth of adjacent rails, so as to prevent longitudinal movement. The rails were secured sideways by wooden keys.

The other rails shown are in 3 ft. lengths, weighing 61 lbs. each, and their chairs weigh 30 lbs. each. The driving wheel is 38 in. pitch diam., and has twenty teeth 6 in. pitch.

684. Early rolled rail. Presented by C. E. and C. Stretton, Esqs., 1903. M.3307.

This example of a single-headed rail is a development of a form patented by J. Birkinshaw in 1820, there being better provision for securing it in the chairs.

The head is 1·4 in. wide, and the web, which is 2 in. deep, has a tapered bottom edged by which the rail is held down into its chair by the securing key. The rail weighs 15·5 lbs. per yard, and the chair, which is probably later, weighs 5 lbs.

685. Early single-headed rail. Presented by C. E. Stretton, Esq., 1892. M.2477.

This is a wrought iron parallel rail from Cole Orton, Leicestershire, where it formed part of a line laid along the bed of what had been the Charnwood Forest Canal; the line, however, was never used, and in 1832 some of the rails were taken up and re-laid on the Cole Orton Railway.

The rails were rolled to a T-section with a continuous groove along one side of the web, and were secured in chairs by wrought-iron keys

which fitted into this groove and into corresponding grooves in the chair jaws. The chairs rested on stone blocks to which they were attached by iron spikes driven into wooden plugs. The rail is 15 ft. long, has a lead 1·75 in. wide, and now weighs 25 lbs. per yard; the chairs, which were made in 1832, weigh 16·5 lbs. each and were spaced 3 ft. part.

686. Fish-bellied rail (1825). Presented by Messrs. J. and C. Thompson, 1892. M.2489.

This early wrought-iron rail is similar to those used on part of the Stockton and Darlington Railway in 1825, and this specimen may be from that line.

The first wrought-iron rails, which were in the form of square or rectangular bars, proved to be too narrow, whilst simply increasing their size rendered them too costly to compete with those of cast iron. In 1820, however, John Birkinshaw, the manager of the Bedlington Iron Works, patented an improved construction of rolled prismatic rail, in which the metal was disposed in the form of a wide head and a narrow web, thus obtaining increased bearing and strength with the same amount of material. At the suggestion of John Buddle, the web was afterwards made of elliptical or fish-belly form so as to give greater depth of girder towards the centre of the spans; this was accomplished by using for the first pass a bottom roll having a groove of varying depth, and then completing the rolling by passing the rail flatwise between ordinary rolls.

The rail was rolled in 15-ft. lengths, had square ends, and was fastened by through pins to the chairs, which were secured by wooden pegs to stone blocks, placed 3 ft. apart. The head is 2·25 ins. wide, and the rail now weighs 25 lbs. per yard; the chairs weigh 6 lbs. each.

687. Fish-bellied rail. Lent by the Patent Nut and Bolt Co., 1889. M.2266.

This rail is similar to No. 686 but heavier, and is believed to have been used on the Bolton and Leigh Railway in 1827. It was secured to the chairs by transverse pins through the web, but the inefficiency of the method is shown by the hollows worn under the rail head by the hammering that resulted from the rail not remaining in contact with the tops of the chair jaws. The rail now weighs 28·5 lbs. per yard, and the width of the head is 2·25 in.

688. Rail from Shutt End (1829). Presented by W. O. Foster, Esq., 1884. M.2474.

The Shutt End Railway in Staffordshire was a mineral line, extending from a colliery near Kingswinford to a basin on the Staffordshire and Worcestershire Canal, a distance of 3·12 miles: it was opened on June 2nd, 1829, by the locomotive "Agenoria," which worked the line for many years and is now preserved in the Central Hall of this Museum (*see* No. 128).

The rail is of the wrought iron fish-bellied type carried in chairs, the jaws of which support the under surface of the rail head; but instead of being held in the chairs by the transverse pins, then usual, the lower

edge of the rail is provided on one side with a projecting ledge which fits into a corresponding recess in the jaw of the chair, while a key in a recess in the other jaw completes the fastening. At the joints the two adjacent rail ends were keyed together into a single chair.

The rail was rolled in lengths of 15 and 18 ft. forming 5 and 6 spans respectively, and weighed about 33 lbs. per yard; it now weighs 29 lbs. per yard and the chairs 7 lbs. each.

689. Views on the Liverpool and Manchester Railway. Presented by Clement E. and C. Stretton, Esqs., 1900. M.3090.

This is a series of hand-coloured aquatints, drawn by T. T. Bury, and published by R. Ackermann, with descriptive letterpress, in 1831.

A tramroad or railway between Liverpool and Manchester had been proposed and a route surveyed for it in 1797 by W. Jessop, and in a modified form in the following year by B. Outram. A more direct route was adopted in a scheme prepared in 1822, and embodied in an unsuccessful application made to Parliament in 1825. The opening of the Stockton and Darlington Railway, however, caused the project to be revived, and an Act (a copy of which is shown in an adjoining case) authorising the construction of the line was obtained in 1826. George Stephenson, who had laid out the Stockton and Darlington Railway, was the engineer, and the line, which was much more direct than those previously proposed and only 31 miles in length, was opened for public traffic on September 16th, 1830. In 1845 it was amalgamated with the Grand Junction Railway, and these in the following year became part of the London and North Western system. The line was double throughout with wrought-iron rails in 15 ft. lengths (*see* those under the "Rocket," Nos. 129 and 690), 13 miles of which rested on sleepers of oak or larch and 18 miles on stone blocks, the latter being used in cuttings. The gauge was 4 ft. 8·5 in. and the ruling gradient 1 in 89, the steep inclines into Liverpool being worked by stationary winding engines at Edge Hill.

At Liverpool there were three stations—one at Queen's Dock, which has been absorbed by the present Wapping goods station, another at Crown Street, now also a goods station, while the third has developed into the present Lime Street station. From these stations the line proceeded through three tunnels to Edge Hill, where they joined; from thence the railway proceeded to Manchester, where it terminated at the present Liverpool Road goods station, which served also as the passenger station till the line was extended to the Exchange.

The total number of bridges on the line was 63, of which 33 were of brick or stone, 19 of wood and masonry, and 11 of wood alone.

690. Rail and chairs (1829–33). Presented by C. E. Stretton, Esq., 1894. M.2475.

These formed portions of the main line of the Liverpool and Manchester Railway, upon which the famous Rainhill competition took place in 1829. The early locomotives "Rocket" and "Sans Pareil," which both competed there, are now in the Central Hall and standing on similar metals from the same line. The rails are of wrought iron, of the fish-bellied type, secured to the chairs by iron wedges and held down by a side rib.

The chairs differ in size, and vary in weight from 15 to 17 lbs. each, the lighter ones being the earlier, but those for use on wooden sleepers have a larger base area than those for stone blocks; each chair was secured to its sleeper by two iron spikes. In 1833 a new pattern chair was introduced in which the keys were inside and there were specially wide joint chairs, two of which are shown, weighing 24 and 31 lbs. respectively.

The sleepers used on embankments were half-round wooden cross ties 9 ft. long, while in cuttings the chairs were carried on stone blocks 20 in. square by 10 in. deep to which they were secured by spikes driven into wooden plugs forced into holes in the stone. In the Olive Mount cutting the chairs were originally spiked directly to the rock bottom, but, owing to the breakage of rails and chairs caused by the excessive rigidity, wooden sleepers were afterwards interposed. The fish-bellied rails, however, continued to break near the chairs and they were soon abandoned, the change to parallel rails weighing 50 lbs. per yard being in progress in 1834.

The rail shown is 15 ft. long covering five spans of 3 ft.; it is 2·25 in. wide, 2·5 in. deep at the chairs, and 3·5 in. deep at mid span. It originally weighed 35 lbs. but now weighs 31 lbs. per yard.

691. Fish-bellied rails. Presented by Messrs. J. and C. Thompson, 1892. M.2490–2.

These are of wrought iron, with the joints made at the chairs.

The first rail is of symmetrical section and was fixed in each chair by an iron key so arranged as to hold it down as well as to secure it laterally. The joints were made in the chairs by such keying, but the ends of adjacent rails were also rebated off so as to form the half lap joint patented by Messrs. Losh and Stephenson in 1816. By this arrangement the serious jolting that occurred when the wheels passed over the gap between the rail ends was greatly reduced, but the fastening did not entirely prevent difference of level between the rail ends. The rail now weighs 27 lbs. per yard and the chairs 10 lbs. each.

The second is a deep rail with half-lap joints, but is furnished at the under side of the web with rounded projections which fit into cavities in the chairs, after the manner patented by Mr. W. Losh in 1828. This arrangement was intended to secure uniform bearing, even should the stone blocks settle irregularly, and it was adopted on the Newcastle and Carlisle Railway. The rail is rolled with a pair of wide grooves along the web, and is secured by a key on each side fitting into corresponding grooves in the chairs; it now weighs 33·5 lbs. per yard, and the chairs 13 lbs. each.

The third rail is similar to the Liverpool and Manchester rail of 1829, but is carried on wide-based low chairs, probably to obtain increased stability. The rail now weighs 30·5 lbs. per yard, and the chairs 11 lbs. each.

692. Rail crossing or "frog," 1832. Presented by the Bagworth Colliery Co., 1903. M.3309.

This cast iron crossing was employed on a branch line laid in 1832 by Lord Maynard from the Leicester and Swannington Railway to his collieries; it is, however, very similar to those in use on the main

lines of the period until, with the increase in speeds, the construction was found to be unsafe for general traffic.

The crossing consists of a flat bed having raised portions forming continuations of the lines of rail with spaces between, for the passage of the wheel flanges, while two raised outside guards are also provided which prevent the wheels leaving the track when passing the gap. The crossing is 4·25 ft. long by 1 ft. wide, and has an angle of 10 degs.; it was spiked down to sleepers, and the rails, which were held in their separate chairs, simply butted against its ends.

693. Combined plate and rail. Presented by the Midland Railway Co., 1893. M.2539.

This wrought iron rail is from the Cloud Hill tramway of the Ashby Canal Co., and was laid down in 1833 to replace the plate rails previously in use, so as to obviate a break of system at the junction with the Cole Orton Railway (*see* adjacent ordnance map).

The rail is a combined plate and edge rail, flat wheels running on the plate and flanged ones on the raised ledge. It was rolled in 15 ft. lengths, and now weighs 41 lbs. per yard. The lengths were dovetailed together, and were fixed in chairs on stone blocks or wooden sleepers at 3 ft. centres, with a rail gauge of 4 ft. 8·5 in. and the plate portion inside.

694. Early permanent way. Presented by D. Drummond, Esq., 1902. M.3252.

These portions are from the Bodmin and Wadebridge Railway, a Cornish mineral line, about 15 miles long, and of standard gauge, built in 1834. Further particulars of the undertaking are given in connection with the views of its passenger carriages (*see* No. 762).

The permanent way consisted of granite block sleepers about 20 in. sq. by 12 in. deep, spaced at 3 ft. centres, while at intervals there were transverse blocks 6 ft. long, which acted as ties; each sleeper carried a cast iron chair (now weighing 10 lbs.) secured to it by spikes driven into holes that had been plugged with wood. The rails are of wrought iron and of a uniform depth of 3·5 in., while the shape of the section approaches the present bull-headed form, the head being 2 in. wide and the foot 1 in., while the web is ·5 in. thick; these rails weighed 42 (now 32) lbs. per yard, and were connected by a half-lap joint made in a chair.

695. Early wrought iron rail. Presented by Messrs. J. and C. Thompson, 1892. M.2488.

This example of a parallel rail with a small lower flange was designed in 1835 by Mr. Daglish, who was awarded a premium for it by the London and Birmingham Railway Co. The chairs, which were carried on stone blocks, closely fitted the web of the rail, and were threaded on from the end; there were, however, spaces left above the lower flange for the reception of a pair of keys by which it was secured. The rail now weighs 28 lbs. per yard and the chairs 10 lbs. each.

696. Views on the London and Birmingham Railway. Presented by C. E. and C. Stretton, Esqs., and John Hyde, Esq., 1900. M.3091-2.

This is a series of lithographs drawn by Mr. J. C. Bourne while the line was under construction, and published with descriptive letter press in 1838–9.

A railway between London and Birmingham had been projected as early as 1824; but, through opposition and the introduction of alternative schemes, it was not until 1833 that the Act authorising its construction was obtained, while the extension from the original terminus in Hampstead Road to Euston Square was only sanctioned in 1835. Part of the line was opened in 1837, and the whole 112·5 miles on September 17th, 1838. In 1846 the line was amalgamated with the Grand Junction and the Birmingham and Manchester Railways, the united systems becoming the London and North Western Railway.

A double line of standard (4 ft. 8·5 in.) gauge was provided for, and a ruling gradient of 1 in 330 adopted which, together with curves of not less than 27 chains radius, necessitated very heavy earthworks, so that the total cost of the undertaking with its equipment exceeded £50,000 per mile.

The adjacent coloured aquatints form part of a series of views of the finished works drawn by T. T. Bury and published by Ackermann and Co. in 1837.

697. Single-headed girder rail (1838). Presented by C. E. Stretton, Esq., 1892. M.2483.

The uniform T-section rail was first rolled in 1820, by Birkinshaw, but was re-introduced by George Stephenson about 15 years later on his abandoning the elliptical pattern, after experience had shown its unsuitability; his reason for preferring the T to the double-headed section, advocated by Locke, was that he anticipated the wear of the lower head of a reversible rail, where resting in the chairs would render inversion impracticable.

The specimens shown were laid down in 1838 at Hampton-in-Arden, on the Birmingham and Derby Junction line, which was opened in 1839 and now exists as a portion of the Midland system. The deep parallel web of the rail is provided with a longitudinal groove for keying, and the joints were made by lapping, without, however, cutting the webs. The rails were secured in the joint chairs by a small iron ball on each side wedged up by split cotters; in the joint chairs shown, however, which are probably later, the rail ends are secured by through pins. The intermediate chairs are of two forms, in one of which the rail is held by a single ball and cotter, and in the other by a plain iron key.

The rails were rolled in 15 ft. lengths, weighing 56 lbs. per yard, and the chairs were spiked to wooden cross sleepers placed 2·5 ft. apart. The intermediate chairs weigh 19 lbs. each and those at the joints 28 lbs.; the original joint chairs weighed 24 lbs. each.

698. Parallel rail (1839). Presented by Messrs. C. E. and C. Stretton, 1904. M.3324.

This is a portion of the permanent way designed by Messrs. Vignoles and Woodhouse, which was laid on the Midland Counties Railway

between Syston and Leicester in 1839. The rail was rolled with a very wide upper flange but a narrow lower one, and was secured, by wooden keys, into chairs which were spiked down to wooden cross sleepers or stone blocks. The joint was made by keying the adjacent rail ends together in a chair of extra width.

The rails were in 15 ft. lengths, and had the head 2·75 in. wide; the specimen now weighs 51·5 lbs. per yard. The chairs were placed 5 ft. apart, and the intermediate ones shown weigh 19 lbs. each.

699. Flat-footed rail (1840). Presented by C. E. Stretton, Esq., 1892. M.2476.

This piece of rail and the two chairs formed part of the permanent way of the Birmingham and Gloucester Railway, opened in 1840, which was probably the first line to use chairs for securing flat-footed rails. Capt. W. S. Moorsom, the engineer to the company, on returning from America, wished to use flat-footed rails spiked to sleepers in the usual manner, but the Directors, considering this attachment insecure, insisted upon the addition of chairs into which the rails were fixed by wooden keys. In 1865 some of these rails were sold to the Groby Granite Company, by whom these specimens were used until their presentation to this Museum.

The rails were laid on longitudinal timbers in cuttings, with chairs 5 ft. apart and bearing plates midway between; on embankments above 5 ft. in height, half-round cross sleepers were used, spaced 2·5 ft. apart. The rails were in 15 ft. lengths, weighing 56 lbs. per yard; the intermediate chair weighs 17 lbs. and the wider joint chair 21·5 lbs.

700. Rail, joint, and chairs (1840). Presented by the Midland Railway Co., 1893. M.2536–7.

This is a portion of the permanent way laid on the North Midland line between Derby and Leeds in 1840. The rail is of a reversible section and was jointed in the wide chair shown—the usual arrangement till the adoption of fish plates, which were introduced by Mr. W. B. Adams in 1847. Wooden keys were employed to fix the rails, and the chairs were secured to transverse wooden sleepers by two wooden trenails. The rail in its present condition weighs 57 lbs. per yard, the ordinary chairs 21·5 lbs. each, and the joint chair 22 lbs.

701. Parallel rail (1848). Presented by Messrs. J. and C. Thompson, 1892. M.2493.

This rail, which was in use at Kirkhouse in 1848, is of the bull-headed variety, but has the lower bulb greatly reduced and the internal angles so filled in as to give the web a continuous curve, possibly to facilitate rolling. It was secured by wooden keys to chairs which were attached to stone block sleepers, placed 2·5 ft. apart between centres; the joints were square butts meeting in a wide chair and there keyed. The rail now weighs 46 lbs. per yard, the intermediate chair weighs 19 lbs., and the joint chair 25 lbs.

702. Rail and chairs (1850). Presented by C. E. and C. Stretton, Esqs., 1903. M.3304 and 3326.

This is a specimen of the permanent way laid by Mr. W. H. Barlow on the Midland Railway in 1850. The rail is double-headed and had originally much-rounded faces; it was rolled in 20 ft. lengths and weighed 80 lbs. per yard. The joints were fished, while wooden keys secured the rails in chairs, which were each fastened to wooden cross sleepers by two spikes. The rail now weighs 68·5 lbs. per yard, and the chairs 26 lbs. each.

703. Barlow's cast-iron sleeper. Presented by the Midland Railway Co., 1893. M.2538.

This formed a portion of the permanent way of the Leicester and Swannington Railway, near West Bridge, where it was laid down about 1850 and remained in use till 1893. The arrangement had, however, been long abandoned on important sections, as after a thorough trial it was found that with the increasing axle loads these sleepers frequently broke.

The sleeper, which was patented in 1850 by Messrs. P. W. and W. H. Barlow, consists of a long inverted trough of cast-iron, closed at the ends, with two chairs cast on it and a socket into which is pinned a heavy wrought-iron tie-rod. These sleepers were arranged longitudinally, and with their chairs weighed 160 lbs. each.

704. Compound-rail (1851). Presented by W. B. Adams, Esq., 1858. M.202.

This is one of many forms of girder rail patented by Mr. Adams in 1851, 1854 and 1856. It is a single-headed rail and rolled with a deep web finishing below in a small moulding. On each side of the web is riveted a wide angle-iron which, when the rail was bedded in the ballast, would give the requisite bearing surface. If used on transverse sleepers, the web and angle-irons were to be let into them. Its weight is 132 lbs. per yard.

705. Rail and chairs, 1857. Presented by C. E. and C. Stretton, Esqs., 1903. M.3305.

These formed a portion of the permanent way laid in 1857, on the line between Leicester and Hitchin. The rail is of reversible section and was rolled in 20 ft. lengths, which were jointed by fish-plates. The chairs were secured to transverse wooden sleepers by two spikes, and the rails were fixed by wooden keys placed at the inner side of the rails. This method of keying was adopted with the object of maintaining the gauge even if the keys loosened; after some years' trial, however, it was decided that considerable breakage of the chair jaws resulted therefrom and since about 1884 the Midland Railway Co. has abandoned it in favour of the usual outside keying.

The rail now weighs 75 lbs. per yard (originally 80 lbs.), the chairs 32 lbs. each, and the fish-plates 21·5 lbs. per pair.

706. Railway chair and rail joint. Presented by James Morris, Esq., 1861. M.208.

This joint was patented by Mr. Morris in 1857, and was for use with reversible double-headed rails. It is made by keying into a special chair, rubber insertion being also added.

707. Elongated joint chair. Contributed by R. J. Badge, Esq., 1858. M.211.

This arrangement, patented in 1857 by Mr. Badge, is a combined fish-plate and chair. It is composed of two equal and similar pieces, which are bolted together through the rails ends and act as fish-plates, while the bottom edges of these plates are enlarged so as to form feet for securing them to the sleeper. The nuts are prevented from slacking back by a small wedge, driven between the under side of each nut and a projection on the chair.

708. Wrought iron rail. Presented by Messrs J. and C. Thompson, 1892. M.2494.

This is a parallel double-headed wrought iron rail with a fish-plate joint, and represents the general pattern in use before the introduction of steel. Weight per yard 56 lbs., weight of chair 22 lbs. Steel rails were first used experimentally in 1862, with steel at £15 per ton, but even at that price proved economical through their great endurance. Since 1870 steel has gradually replaced iron, so that now wrought iron rails are becoming as scarce as those of cast iron.

709. Bridge rail. Contributed by Thomas Ellis, Esq., 1862. M.778.

The feature of this rail, patented by Mr. Ellis in 1861, is that when being finally rolled the flanges are closed together so as to leave no longitudinal space, the intention being to secure better bearing surface. It is believed to have been used on the Great Western Railway. Its weight is 23 lbs. per yard.

710. Rail and chair (1875). Presented by C. E. and C. Stretton, Esqs., 1904. M.3325.

These were known as the improved Settle and Carlisle patterns, and were laid on the Midland Railway in 1875. The rail is of steel, bull-headed, weighed 83 lbs. per yard, and was rolled in 24 ft. lengths; the joints were fished. The rails were secured in the chairs by wooden keys placed on the inner side of the rail, whilst each chair was fastened to its wooden cross sleeper by two trenails and two spikes. The rail now weighs 70 lbs. per yard, and the chair 39 lbs.

711. Rail, joint and chairs (1893). Presented by the Midland Railway Co., 1893. M.2540.

This is a specimen of the permanent way used on the main line ot the Midland Railway in 1893. Two short lengths are shown jointed together with the standard steel fish-plates and bolts, the nuts of which

are prevented from slipping back by a locking arrangement which consists of four radial slots on the outer face of the nut, by which a certain elasticity is given to the nut. Two of the company's chairs are also shown, each of which is secured by two spikes and two trenails to transverse sleepers. The rails, which are of steel and cut to 30 ft. lengths, weigh 85 lbs. per yard, and the cast iron chairs 50 lbs. each. The sleepers are rectangular, 9 ft. long, 10 in. wide, 5 in. thick, and are placed at distances of 2·78 ft. centre to centre, reduced to 2·17 ft. where there is a joint intervening.

712. Bowl sleeper (1859). Presented by Messrs. Ordish and Le Feuvre, 1862. M.853.

The bowl sleeper was first patented in 1846 by Mr. H. Greaves and was soon afterwards successfully used by Robert Stephenson in Egypt.

It is an inverted spherical bowl in cast iron with the jaws of a chair formed upon it, and is provided with two side holes by which ballast can be packed within. One jaw of the specimen shown is provided with vertical serrations for use with the spring key patented in 1859 by Mr. R. M. Ordish. The weight of the casting is 91 lbs.

713. Bowl sleeper. Presented by Messrs. Wilsons, Pease and Co., 1895. M.2757.

This sleeper is used on some Indian railways. It consists of an elliptical cast iron bowl, with lugs on the upper surface forming the jaws of a chair for holding a flat-footed rail. The rail is secured by a wooden key, and rests on bearers at the extremities of the bowl. The gauge is maintained by a wrought iron tie, held in a transverse socket formed in the casting. Two holes are provided for packing the ballast into the bowl. The sleeper weighs 64 lbs.

714. Plate sleeper. Presented by Messrs. Wilsons, Pease and Co., 1895. M.2756.

This form of metal sleeper was first patented in 1853 by Mr. C. de Bergue, and was tried on several British lines; it was found, however, that the arrangement, although reducing the first cost, was not so suitable for heavy traffic as wooden sleepers carrying chairs.

The modern example shown, which is used on some lines in Spain, consists of a rectangular cast iron plate with a central rib below, modified to receive and retain a notched tie of wrought iron. The plate is extensively ribbed on its upper surface, and the flat-footed rail used is supported on four of the transverse ribs, while ledging against a longitudinal one. There are no chairs, the rail being secured by a clip held down by a bolt; this bolt also fastens the tie rod which passes through a slot in its shank. The sleeper weighs 62 lbs.

715. Steel sleeper and chairs. Lent by F. W. Webb, Esq., 1888. M.1938.

This is a portion of the permanent way patented by Mr. Webb in 1879, and laid down experimentally on the London and North Western Railway in 1884.

The sleeper is of steel plate, pressed into a trough form to give stiffness, and with the ends bent down to retain the ballast and prevent lateral movement. The chair jaws are steel stampings riveted to the sleeper, but with an interposed plate and two beddings of tarred felt. The bull-headed rail used is secured by the usual wooden key or by the spring steel key shown in one of the chairs.

716. Chairs and sleepers in forged steel. Presented by James Muirhead, Esq., 1897. M.2979.

This construction of forged chair was patented by Mr. A. E. Muirhead in 1894. A suitably rolled or stamped billet of steel is taken and so cut as to leave two flaps, which when bent upward will form the jaws of the chair. With flat-footed rails shallow jaws only are necessary, between which the foot is secured by a metal key. These chairs are cut from a billet having a central rib, which on either side of the jaws is flattened down, so increasing the bearing surface. If the chairs are simply held by iron ties without sleepers the ends are bent down and slotted as shown The combined sleeper and chairs for double-headed rails have the rails secured by the usual wooden key, but otherwise are free from joints and loose parts. It is claimed that a forged steel chair weighing 24 lbs. is considerably stronger than a cast iron one of 41 lbs. weight.

717. Model of Wood's steel sleeper and rail fastening. (Scale 1 : 2.) Lent by C. Wood, Esq., 1893. M.2549.

The sleepers are of steel and of the trough section, slightly open at the extreme edges. The rails are of the flat-footed type, and no chairs are used. The fastening consists of a steel clip of a C form, which is passed upward through two slots punched in the sleeper. One extremity of the C hooks on to the foot of the rail and the other receives the wooden key, which is driven in between it and the web and foot of the rail, so tightening the whole simultaneously.

718. Howard's steel sleepers. Made by Messrs. J. and F. Howard. Received 1895. M.2896.

Two forms of these sleepers for light or portable railways are shown; the rail used is flat-footed and the sleeper consists of a steel plate corrugated upwards along the centre, and curved downward at the edges. The centre corrugation is cut away at two places, so leaving jaws. Into these the rails are fitted and secured by metal keys, which have notched sides to prevent working back. For joint sleepers, or for heavy work, two corrugations are formed on each sleeper; in addition to forming the chair the corrugation greatly stiffens the plate.

719. Steel sleeper and rails. Presented by Messrs. W. G. Bagnall, Limited, 1899. M.3058.

These are part of a narrow gauge line suitable for being worked by a six-wheeled locomotive weighing 20 tons.

The sleeper is of steel plate ·25 in. thick, and by pressure is given two longitudinal corrugations, while at the same time the ends are turned down.

The rails are flat-footed, and weigh 41 lbs. per yard; they are held between clips, pressed up from the solid plate, and secured by a key. These sleepers were patented by Mr. W. G. Bagnall in 1889.

720. Models of portable railway plant. (Scale 1 : 8.) Lent by Messrs. John Fowler and Co., 1892. M.2427.

Portable railways of gauges from 16 in. to 30 in. are frequently employed when the traffic is not sufficiently permanent to warrant the construction of an expensive road. The rails and metal sleepers are bolted together, forming complete sections of 15 ft., which can be rapidly moved or laid down on the surface of the ground. Horses or men usually do the hauling on the lighter lines, and small tank locomotives on the heavier.

These models show various details of Mr. Greig's portable railway. The steel rails are flat-footed, weighing from 10 lbs. per yard upwards, in 15 ft. lengths, and carried on corrugated steel sleepers spaced at 3·75 ft. centres, but more closely where the ground is bad. Each sleeper has a deep longitudinal corrugation pressed into it, and at the ends is riveted a steel chair, cut from a bar so rolled as to fit closely the flange and web of the rail on one side. The rail is held into the chair by a hook bolt, which grips the inner edge of the rail flange and passes under the rail and chair by the groove in the sleeper to the end, where it is tightened up by a nut. The lengths are joined together by sleepers of double width and two corrugations, the long chairs acting as fish-plates, but the rails are not drilled, hook bolts being employed throughout. A turntable and crossings are also shown, in which the method followed is to make up such pieces complete, and finish with the ordinary attachments. A short length of inclined rail is used instead of points when a temporary branch only is required. The trucks shown have channel iron frames and timber stanchions. In one case the channel iron is carried round to form the buffers, and the draw-bars swivel on a pin attached below the platform at the centre, so that the animal employed in hauling can pull from the side of the line without risk of derailing.

721. Model of mixed gauge railway. (Scale 1 : 24.) Received 1882. M.1834.

This is a model made in 1839 by Mr. B. Smith, of Carnarvon, to illustrate his proposal for reducing the inconvenience of the mixed gauges. It shows a portion of the London and North Western line to Holyhead, but in addition to the ordinary narrow gauge rails, a complete broad gauge system is also introduced. To accommodate itself to the existing platforms and other structures the system required a fresh type of railway stock, consisting of a narrow gauge body on broad gauge wheels, the wheels being in this case outside the frames. Models of carriages constructed in this way, as well as of the standard broad and narrow gauge carriages of that period, are shown; and, now that the broad gauge has disappeared, the comparison of these models with modern rolling stock may be of interest.

Mr. Smith's scheme was to alter the narrow gauge to the broad gauge, but time has shown that the conversion was to be made in the reverse direction.

722. Sliding-rail switch. Presented by C. E. and C. Stretton, Esqs., 1900. M.3111.

This is from the Leicester and Swannington Railway (1832–46), and illustrates a kind of switch much employed at that period. The rails are of the fish-bellied pattern, but the portion arranged for shifting is a 2 in. square bar, 11·8 ft. long, riveted to a length of 6·5 in. by ·5 in. flat; it is pivoted at one end, and the other would be attached to a rod moved by an eccentric on the end of a vertical shaft, as shown in adjacent views on the London and Birmingham Railway in 1838, and by a model. The double and half chairs necessary for the switch are also shown.

723. Model of sliding or stub switch. (Scale 1 : 12.) Made in the Museum, 1902. M.3231.

This shows the complete arrangement of the class of switch in common use in England till about 1850, and still employed on some of the Colonial branch lines. The type is also represented in the lithographs of the London and Birmingham Railway (*see* No. 696), and there are portions of an actual switch of this kind from the Leicester and Swannington Railway of 1832 (*see* No. 722).

The model shows a three-way switch in use in Belgium in 1858. The rails are of a double-headed pattern, but the portion arranged for shifting is of square bars riveted to flat plates, which slide on iron bearers arranged transversely on longitudinal sleepers. The square rails are each pivoted at one end, and attached by a rod near the other to a crank in a vertical shaft, which can be locked in the three working positions. With only two roads the crank-throw limited the two positions without accurate locking, but with three roads the intermediate position introduced a serious element of danger. This form of switch was sometimes arranged with a movable portion for each road, so as to distribute the wear over several pivoted bars.

724. Model of facing points (working). (Scale 1 : 4.) Contributed by Messrs. Wilkinson and Crowther, 1875. M.1374.

These facing-points, patented in 1873, are intended to be locked in either position by a long, heavy sliding block, moved by a second lever (independent of the lever for moving the point), which is, in fact, an old "shifting-rail."

725. Compressed trenails and keys. Contributed by Messrs. Ransome and May, 1857. M.79.

These specimens were made by the process patented by Messrs. J. Ransome and C. May in 1841, for the preparation of the trenails and keys for fixing railway chairs to the sleepers and the rails in the chairs; they were first used on the South Eastern Railway. Prior to this invention the trenails and keys were compressed, so that they should expand when in position and remain fast, by driving them through iron rings or dies; unless used immediately, however, they were found to have regained their original size to such an extent as to be unreliable.

In the improved process the oak, or other hard wood blocks are forced into iron moulds by a powerful press, and then baked in an oven for several hours, so that when removed from the moulds they retain their reduced size. After being driven into the sleepers or chairs they absorb moisture and swell sufficiently to insure a firm hold. The compression reduces the bulk of the trenails 37 per cent. and of the keys 20 per cent.

726. Barlow's iron key. Presented by the Midland Railway Co., 1903. M.3311.

This form of railway chair key, patented by Mr. W. H. Barlow in 1844, was introduced to replace the wooden keys which, although satisfactory in the intermediate chairs, frequently became loose or suffered damage through the rocking of the sleepers when used in joint chairs.

Barlow's key consists of a strip of iron plate bent to form a flattened tube, with the joint open or else closed by welding; it accordingly possesses some elasticity with great strength and durability, and was found to be very effective in stiffening the joints. These keys were first used on the Midland Counties Railway, but, owing to the introduction of jointing by fish-plates shortly afterwards, were never extensively adopted. In recent years they have been employed in some of the "all metal" permanent ways.

The example shown was in use till 1903, and now weighs 3 lbs.; it is 6 in. by 3·5 in. by 1·75 in. and the metal is ·25 in. thick.

727. Railway key fastening. Contributed by E. Gatwood, Esq., 1860. M.395.

A chair and piece of double-headed rail are shown, having the wooden key fitted with a fastening to prevent slacking back as the wood shrinks. The fastening consists of a strip of sheet steel split at the end, and with the tongues bent in opposite directions, so that one catches the chair while the other is slightly embedded in the smaller end of the key.

728. Goodwin and How's key clip. Lent by Messrs. Turton Bros. and Matthews, 1890. M.2304.

This clip is designed to prevent the wooden keys employed to secure railway metals in their chairs from working back, owing to the vibrations caused by passing trains, and the shrinkage due to the action of the weather.

The specimen shows a modern chair, with a short length of rail keyed in position, and the key secured by the clip. The clip is stamped from flat steel, and the ends bent over to secure it in the chair. Two spring tongues are formed in the middle of the clip, and these, while offering no resistance to the insertion of the key, act as ratchet pawls, and dig into the wood when any movement is attempted in the reverse direction. Rails so secured have been known to creep ·75 in. against the keys without any slackening taking place. When necessary, however, the keys can be removed by a heavy hammer.

729. Spring washers. Presented by Messrs. Grover and Co. 1890. M.1766 and 2329.

Spring washers were introduced in 1873 by Mr. J. W. Grover as a means of preventing nuts from slacking back under vibration; they have been extensively used for the fastenings of fish-plates.

The washer consists of one turn of a helix, made in tempered steel, with the ends so bevelled that screwing down the nut simply flattens the helical turn into a ring, but the reverse motion causes them to cut into the surface of the nut and the fish-plate. The washer is made from a piece of steel of the required length, which is gripped between a lever and a mandrel and bent whilst hot between two helical cheeks. In 1886, however, Mr. Grover introduced a modified form of the washer, by making it from rod of H-section, with the object of obtaining increased compressive resistance without adding to the weight.

730. Locking washer. Lent by Messrs. J. H. Ladd and Co., 1888. M.1885.

This is a spring washer patented in 1886 by Mr. H. A. Harvey. It consists of a cylindrical steel washer, cut through radially in one place and then bent to form a helical surface, so that the sharp ends of the section tend to prevent rotation of the nut. The upper face of the washer has a central conical projection, while the middle portion of the nut face is correspondingly recessed, so that in screwing home the nut the washer, in addition to being flattened, is also closed upon the thread of the bolt and thus caused to grip it.

731. Lock nut. Presented by D. Halpin, Esq., 1885. M.1621.

This nut, patented by Mr. Halpin in 1879, is about double the ordinary length and is given a certain amount of elasticity by having a saw cut made parallel to its axis and extending about half-way down. The cut portion is then closed in, so that, when screwed on, the bolt has to expand the outer end of the nut against the elasticity of the material, and in this way any shaking is prevented.

732. Lock nut. Presented by T. K. Mellor, Esq., 1884. M.1617.

In this nut-locking arrangement, patented by Mr. Mellor in 1884, two longitudinal grooves are cut through the thread of the bolt, and two inclined holes are drilled through the nut from its side to its thread; a piece of wire passed through one of the holes can be forced along the groove in the bolt, and then bent so as to retain itself in position, while also acting as a key between the nut and bolt. The holes in the nut are 90 deg. apart, and the grooves in the bolt being opposite, there are four points in each turn in which the nut can be locked.

733. Bolt and locked nut. Lent by W. Armstrong, Esq., 1889. M.2274.

This arrangement of locked nut was patented by Mr. Armstrong in 1887. An ordinary hexagonal nut is used, but the outer end of the bolt is reduced to a square section and fitted with a washer having a

square hole in its centre and provided with two lugs which are bent down to hold the nut. When the nut is screwed home this washer, or cap, is slipped on and retained by a split pin beyond it.

734. Lock nut. Lent by Messrs. Ibbotson Bros. and Co., 1888. M.1884.

Two forms of this nut are shown, but the action is the same in both cases. The nut is similar to that of Mr. Halpin, but has two saw cuts instead of one. This form of lock nut has been extensively adopted for permanent way, but to prevent the formation of rust in the saw cuts it has been found well to fill them up with thick grease.

735. Lock nut. Lent by Messrs. Bayliss, Jones and Bayliss, 1888. M.1914.

This arrangement was patented by Mr. S. Bayliss in 1887. The nut is forged with an annular projection or lip, which by caulking can be embedded in the metal of the bolt.

736. Lock nut and washer. Lent by the Patent Rivet Co., 1889. M.2278.

The device here adopted for preventing the slacking back of the nut was patented by Mr. J. K. Hargrave in 1888, and is a combination of a special nut and washer. The lower face of the nut is formed with a step and a helical surface, and the upper face of the washer is similarly constructed, the pitches of the helices, however, being greater than that of the thread of the bolt. When being screwed on, the nut rotates the washer by the direct contact of the steps, but afterwards, should the nut attempt to unscrew, and provided that the washer does not rotate with it, the bolt is tightened up by the resulting differential screw action. The washer is made hexagonal in order that both nut and washer may be unscrewed together by a spanner, while to prevent the accidental rotation of the washer its lower face is made concave, so that the corners shall bite into the metal fish-plate.

737. Helicoid lock nuts. Presented by the Helicoid Lock Nut Patents Co., 1899, and Messrs. Bayliss, Jones and Bayliss, Ltd., 1904. M.3078.

These specimens show the construction and method of manufacture of an elastic nut patented by Mr. T. Gare in 1892, for the purpose of preventing slacking back by vibration.

The nut consists of a short length of a closely wound helix which is tapped with a thread of very slightly less diameter than that of the bolt it is to fit, so that screwing the nut on to the bolt causes the helix to expand.

The nuts are made from a mild steel bar of trapezoidal section, which is wound, while cold, as a left-handed helix upon a central mandrel in a coiling machine resembling a lathe. The distortion of the bar in winding alters the section of the steel to a rectangle so that a close coil is obtained; the mandrel is, however, easily released by slightly reversing the twist. This tube is then cut by circular saws into lengths sufficient for single nuts, which are tapped with a thread of the same

pitch as, but of slightly smaller diameter than, Whitworth's standard. If the square or hexagonal shape is required the nuts are passed through a shearing press, which, in two stages, removes segments so as to leave the faces required; the chamfering and finishing are performed in a subsequent operation.

738. Rail lifter. Lent by Messrs. De Bergue and Co., 1892. M.2464.

This is a form of screw-jack, for lifting rails that have settled, thus avoiding the use of the long and inconvenient lever otherwise necessary. It is placed on the ballast and under the rail, and will lift the rail and the adjacent sleepers, so enabling the ballast to be repacked where necessary.

It consists of a wide cast-iron shoe, to give sufficient bearing on the ballast, enclosing a wrought-iron lever, having its fulcrum at one extremity and at the other containing a bronze nut through which works a screw, bearing on the shoe. Handles are fixed for carrying, and a T key for turning the screw is provided, by which one man can exert sufficient power to raise any rail or point. The weight of the lifter complete is 66 lbs.

739. Model of turntable for rolling stock. (Scale 1 : 12.) Contributed by T. Dunn, Esq., 1857. M.71.

This construction of turntable was patented by Mr. Dunn in 1850, and is intended for sidings or warehouse floors where shallow foundations only are permissible. The supporting rollers project above the table, and all parts are accessible from above.

There is but one set of rails, and they are supported on girders connected by cross pieces with the centre pivot; the intervening spaces are planked over.

740. Model of turntable for rolling stock. (Scale 1 : 12.) Lent by the Taff Vale Railway Co., 1896. M.2959.

This table is contained within a cast-iron casing, at the bottom of which is an eight-armed foundation ring that forms the track for the carrying rollers, and also supports the socket for the central pin. The weight of the table is carried by an inner live ring with five rollers and an outer one, which is flexible vertically, having ten rollers.

The table is cast in halves and bolted together; it has a roughened surface and two sets of rails intersecting at right angles. Below, it is ribbed and provided with two roller tracks and also with a central guiding pin.

741. Models of traversers for rolling stock. (Scale 1 : 8.) Contributed by T. Dunn, Esq., 1857. M.76.

The traverser is an arrangement patented by Mr. Dunn in 1847–50 for moving a railway carriage sideways from one line of metals to another, possibly a considerable distance away. It consists of a very low truck, carried on wheels, which run on special transverse rails fixed where the traverser is used. The truck carries two low rails, with hinged tapering ends, or ramps, by which the carriage can be mounted from the main rails to those on the traverser without serious difficulty.

742. Model of a set of railway level-crossing gates. (Scale 1 : 6.) Presented by A. Vickers, Esq., 1862. M.805.

The arrangement was patented by Mr. Vickers in 1859. The four gates are connected by worm wheels and worms on two shafts, driven by two pairs of bevel wheels and a cross shaft. A handle on a spindle with a pinion drives one of the worm wheel shafts by a spur-wheel; the motion of the gates is consequently very slow.

743. Hawksley's stair tread. Contributed by Joseph Westwood, Esq., junr., 1870. M.1196.

This is the original experimental tread laid down at Dalston Station in 1867, and taken up after three years' service, during which time over six million passengers walked over it, with the result that the surface was only lowered ·06 in.

The step consists of a cast-iron grating of small squares, each space being filled in with a renewable block of wood set with the grain on end, flanges at the bottom of each square forming a bearing for the blocks. By placing the wood with its grain in this position the particles of grit on the boots of passengers are pressed into the ends of the fibres, and so tend to harden the surface while giving a secure footing. The blocks are made of oak, pitch pine, or deal, according to the wear that will take place in consequence of their position on the tread.

744. Literature of early railways. Presented by C. E. and C. Stretton, Esqs., 1900. M.3090, 3109.

These comprise maps, guides, regulations, tables of fares, etc., relating to the Liverpool and Manchester, Grand Junction, London and Birmingham, London and Southampton, and other railways.

A copy of Bradshaw's "*Railway Companion*" of 1842 is shown in the same case.

745. Early railway ticket. Presented by C. E. Stretton, Esq., 1888. M.1920.

This ticket was in use on the Leicester and Swannington Railway (*see* No. 140) from 1832 till 1846. It is a bronze casting, and the inscription appears to have been obtained from the mould; the reverse bears simply the number 20. A passenger going to Bagworth from any other station would have such a ticket issued to him, the ticket number and the fare paid being recorded in a book. The guard of the train carried a collecting box having a separate division for each station, and after collecting the tickets returned them to the various stations for future use.

An adjacent photograph shows the West Bridge station and booking office of the line on which these tickets were used.

Street Tramways, etc.

746. Lithograph of early street tramway. Presented by R. B. Prosser, Esq., 1900. M.3115.

Street tramways were first introduced in America, where, owing to the nature of the soil and a scarcity of stone, the roads had given

exceptional trouble. The first line, laid between New York and Haarlem in 1832, underwent considerable vicissitudes, but ultimately the system extended, and by 1850 street tramways were in general use in several of the large American towns.

The first street tramway in England was laid at Birkenhead in 1860 by Mr. G. F. Train, an American merchant. He employed the stepped rail, adopted in Philadelphia in 1855, which had a raised ledge for the flanged wheels of the cars and a wide plate for the wheels of ordinary vehicles, thus resembling the double-purpose rail used in colliery districts as early as 1833 (*see* No. 693).

The tramway shown in the lithograph was from the Marble Arch to Notting Hill Gate, and was laid down by Mr. Train and opened in March, 1861; he also laid similar lines from Westminster Bridge to Kennington Park and from Buckingham Palace to Victoria Station. These schemes had, however, failed to obtain Parliamentary sanction, so that when, owing to the great opposition aroused, the local authorities withdrew their concessions, the whole of the lines were removed, and tramways did not reappear in London till 1869, when the North Metropolitan line was opened.

Mr. Train's rail weighed 50 lbs. per yard, and was 6 in. wide, with a step ·75 in. high; it was fixed to longitudinal timber sleepers, held to a gauge of 4 ft. 8·5 in. by iron ties or timber cross sleepers as shown in the drawing, which is taken from his patent specification of 1860. His cars were very similar to those now in use, and were 16·5 ft. long, 6·5 ft. wide, and 7 ft. high inside, while the wheels were of chilled cast iron and 2·75 or 3 ft. diam.

747. Models of tramway rail and sleepers. (Scale 1:4.) Lent by B. Barker, Esq., 1879. M.1465.

This represents a form of permanent way for street tramways, patented by Mr. Barker in 1876, and laid down about that time in Manchester, Leeds, and other towns.

In this system a grooved rail of T section was supported on longitudinal cast iron sleepers which were practically continuous. Their bases were sufficiently wide to render concrete foundations unnecessary, and also served to support the adjacent paving setts.

The underside of the head of the rail where it rested on the sleeper was indented longitudinally, and the web was accommodated in a slot in the sleeper to which it was secured by transverse cotters. The lower part of the sleeper was a hollow casting with two flanges forming a base 12 in. wide. The total depth of rail and sleeper was 7·75 in. The rail was 3 in. in width, of which 1·5 in. was running surface; the weight was 40 lbs. per yard. The sleepers were 35·5 in. long and placed with ·5 in. spaces between them, but on sharp curves shorter ones were used; they weighed 137 lbs. each.

748. Tramrail and chair. Lent by Isidore Spielmann, Esq., 1879. M.1467.

This form of rail and chair, patented by Mr. S. Aldred in 1877, and improved by Mr. Spielmann in 1879, was used on a portion of the line of the London Street Tramways Co.

The rail is made in halves, which are reversible and have an inclined plane of contact, so that by a single key they are both secured in a

chair; as the halves are so laid as to break joint, they do not require drilling or the use of fish plates. The half rails were in 21 ft. lengths, weighing 32 lbs. per yard, or 64 lbs. together. The chairs were hollow castings 7·5 in. high, and weighed 37·5 lbs. each; they were placed at 3 ft. centres and screwed to transverse wooden sleepers 6·5 ft. long, 9 in. broad and 4·5 in. deep, bedded in concrete. In the later pattern the portion acting as a guard rail was given increased support.

749. Early girder tramrail. Presented by Messrs. L. P. Winby and Co., 1906. M.3465.

This is a specimen of the tramrail used in the system patented by Messrs. F. C. Winby and G. Levick in 1877, and laid down at Nottingham, Bradford and other towns. The rails laid at Nottingham in 1878 were the first girder rails rolled, but this specimen formed part of the line laid at Bradford in 1882. The girder form of rail, now universally used for street tramways, was patented by Mr. C. Burn in 1860, but it was not practically used on account of the difficulty of rolling the section. This difficulty was at first overcome by rolling the guard flange at right angles to the web and then bending it up, but the groove is now pressed in the solid head by an end roller in the finishing rolls.

In Winby's system, the girder rail had a narrow bottom flange and was bolted to a wide base plate in order to obtain a good bearing on the road material and to support the pavement beside the rails. The rail was of steel, 6 in. deep, with a head, 2·9 in. wide, and a running surface of 1·6 in.; the lower flange was 3·5 in. wide, and its weight was 58 lbs. per yard. The base plate was of wrought iron 12 in. wide and ·25 in. thick: it was secured to the rail by cottered bolts. The plates were of one half the length of the rails and arranged to break joint with them. The rails were joined with steel fish plates, and the gauge was fixed by tie bars.

750. Model of a cable tramway. (Scale 1 : 8.) Lent by Messrs. Dick Kerr and Co., 1888. M.1927.

The system of haulage by cable, although successfully applied in mines and on railways for many years, was not tested on street tramlines till 1873, when Mr. A. S. Hallidie and others introduced it on a practical scale in San Francisco, where the gradients are very steep. The first line in Europe worked on this system was the Highgate tramway, started in 1884; Edinburgh, Birmingham and Melbourne are also well-known installations.

The model shows the general arrangement and details of the system as patented by Mr. Hallidie in 1875. An endless wire cable, several miles in length, is driven by a powerful engine at a station somewhere near the line, and travels below the road surface in a tube or conduit provided with a vertical slot at the top, ·75 in. wide and edged on each side by protecting rails; this slot is midway between the ordinary tramlines. The cable is supported at intervals by rollers, and directed by guide pulleys where the line curves, but for the better protection of the rope it is not arranged vertically under the slot.

The cable drives the car by a gripping appliance attached to the car and extending downward through the slot. Two forms of gripper, to the scale of 1 : 4, are shown; in one the relative motion of the two portions of the gripper is obtained by the use of a hand-wheel and screw, by which a wedge-shaped piece causes two jaws to grip or release the cable; in the other the jaws are moved by a combination of hand levers. When the gripper is holding the cable, it pulls it from the pulleys as it passes and thus clears them. The two special advantages claimed for cable haulage are, that in hilly districts the descending cars assist in hauling the ascending ones, and that uniformity of speed is very easily secured.

751. Electric tramway conduit. Presented by Messrs. R. W. Blackwell and Co., Ltd., 1905. M.3395.

This is a section of an early tramway conduit of the form patented in 1888 by Messrs. E. M. Bentley and W. H. Knight, and used on some lines in the United States. Their first line was, however, laid down at Cleveland, Ohio, in 1884.

The conduit system of electric tramways, in which the conductors conveying the current are placed in an underground trough having a slot in the road surface for the passage of the collector, was developed from the cable system and introduced about 1883. Considerable attention was directed to its perfection on account of the objection to overhead conductors, but notwithstanding its safety and unobtrusiveness, its much greater first cost has rendered it inapplicable except in the case of some of the larger cities, including London and New York. The first conduit line in this country was laid down by Mr. Holroyd Smith at Blackpool, in 1885.

The conduit consists of a number of U-shaped cast iron yokes placed 4 ft. apart having their upper ends formed as boxes, level with the roadway. The slot is formed by two rails of obtuse angle section, resting on ledges and bolted to the yokes, the nuts being inside the boxes. The slot is 1·25 in. wide, but the rails may be packed behind to diminish this width. Each yoke box has near the bottom an opening into the conduit, and through this projects a porcelain insulator suspended by an iron bracket and carrying a tongue piece to which the conductor bar is attached. The boxes have movable covers so that the rails and conductors may be removed without disturbing the road surface. Between each pair of yokes is fitted a sheet iron trough forming the inner lining of the conduit and the whole was set in concrete either outside the track or between the rails.

There are two copper conductors 1·25 in. wide by ·25 in. thick, placed 3 in. apart, one carrying the high-tension current and the other forming an insulated return, thus obviating electrolysis. The current collectors or ploughs, of which two were fitted to each car, are flat frames containing insulated cores having at their lower ends steel faced spring contact pieces which bear on the conductors. They have swivel and transverse motions and are mounted on swing frames to enable them to rise out of the slot should any obstruction be met with. The current was conveyed from the ploughs to the motors by cables.

The conduit measures 9 in. wide by 14 in. deep, but in modern examples larger dimensions have been found necessary.

752. Model of an aerial ropeway on the Hodgson-Carrington system. (Scale 1 : 24.) Lent by Messrs. Bullivant and Co., 1890. M.2324A.

The model represents a short section of such a line, but a distance of 3 miles can be covered by the arrangements shown with the addition of extra intermediate supporting sheaves, while by coupling such sections together a length of 12 miles has been attained. The endless wire rope passes round a horizontal pulley at each end of the section, one pulley being driven and the other carried in a sliding tightening frame by which the necessary tension can be given. This travelling rope both supports and hauls the loads, while forming also the up and down lines. The skips hang from shoes which grip on to the wire rope, but the shoes are provided with double-flanged wheels which at the end of the section mount a curved stationary rail, so lifting the shoe clear of the rope and stopping the skip. After discharging, the skip is run round this rail until it is again dropped on to the travelling rope, when it commences the return journey. The intermediate supporting sheaves are overhung from their supports to clear the skips, and the shape of their flanges is such as to offer the least possible obstruction to the shoes. The rope travels at a constant speed of from 3·5 to 4 miles per hour; the loads vary from 1 to 6 cwt., and the capacities of such lines are from 5 to 50 tons per hour.

753. Photographs and details of aerial ropeways on the "Otto" system. Presented by Messrs. Commans and Co., 1892. M.2478.

These wire ropeways have a heavy fixed carrying rope and a light travelling hauling rope, but to secure a return service there are usually two carrying ropes, and the hauling rope is endless and kept continuously moving at a speed of about 3·5 miles per hour. A carrying rope 1·375 in. diam. and a hauling rope ·625 in. diam. are proportions that have been used. The carrying ropes are supported on standards of timber or wrought iron placed at about 200 ft. apart, but spans of 1,000 ft. to 1,600 ft. have been sometimes employed. The carriers or skips are suspended from two-wheeled trollies (as shown) which run on the standing rope, and are provided with a clamp by which the hauling rope can be seized and so caused to move the load. When the delivery station is reached a bar fixed there strikes a lever on the clamp, and so automatically disengages the hauling rope, and the trolley and load by their momentum may run on and up a rigid iron turn-out or shunt where loading or unloading may be carried on. When the inclines do not exceed 1 in 6, a simple frictional grip of the clamp is sufficient; for inclines up to 1 in 3 clamps with corrugated jaws are used, while for still steeper slopes the hauling rope has collars inserted in it which enable the clamps to hold by a positive grip, but in such cases it is desirable to start the load by hand before engaging, so as to reduce the shock. An actual trolley is shown, together with an example of the frictional and of the positive grips employed.

A ropeway in Spain on this system 9·69 miles in length is in four sections, a 30 H.P. engine driving the first two sections, and one of 70 H.P. the last two. There are 660 buckets on the line, and the capacity is 4,095 ton-miles per day of 10 hours.

754. Model of a telpherage line. Lent by the Telpherage Co., 1888. M.1917.

Telpherage is the name given by Profs. Jenkin, Ayrton and Perry to a system of transport by an aerial ropeway, that they proposed in 1882 and subsequently developed. The features of the arrangement are: that the haulage is performed by an electric locomotive, that the line is in short sections of about 66 ft. insulated from each other, and that the length of each train is greater than that of a section. Adjacent sections are oppositively electrified, and the current to the motor is supplied from the line by wheel contact. In a later form a separate trolley-wire was employed to convey the current.

The load is carried in skips, each of which weighs 100 lbs., and conveys a load of 250 lbs. The skips are supported by two flanged pulleys, which are carried in castor bearings to give the flexibility required in turning curves. The track is double and supported on posts about 18 ft. high, the line is of ·75 in. round steel, welded to the post fastenings, which are insulated. The working speed is about 5 miles per hour and the system gives an up and down line, both carried on the same supports.

755. Pneumatic despatch switch. Received 1901. M.3194.

Several schemes had been proposed for transmitting objects by blowing them through a tube by air pressure, but it was not till 1851 that Mr. J. Latimer Clark introduced the method on a practical scale by laying a tube for conveying telegrams for the Electric and International Telegraph Co., between their stations in Telegraph Street, Cornhill, Lothbury, and Mincing Lane. Similar arrangements were installed at Berlin in 1865 and at Paris in 1866, while in 1865 the Pneumatic Despatch Co. constructed a D-shaped tube, 4 ft. high by 4 ft. 6 in. wide, from Euston to Holborn, which was subsequently extended to the General Post Office, for the conveyance of parcels and goods in four-wheeled trucks directly propelled by air pressure.

In 1867 Sir C. W. Siemens patented a pneumatic circuit in which the carriers were driven through the transmission tube in one direction only, so that several carriers could be passing through the tube at the same time, and their propulsion was effected by reducing the pressure in front of the carriers as well as increasing that behind them. In 1870 he laid a return circuit on this system, consisting of two tubes 3 in. diam., between Telegraph Street and the General Post Office, a distance of 852 yds., worked by an air pressure of 7 lbs. per sq. in. above atmosphere and an exhaustion of 5·5 lbs. below.

In 1873, however, Mr. R. Sabine determined that tubes of 2·25 in. diam. and an air pressure of 10 lbs. per sq. in. above atmosphere and an exhaustion of 6·5 lbs. below, would be more suitable, and these are the arrangements that have since been employed. The tubes are of lead, and are enclosed in iron pipes, while the carriers are of gutta percha covered with shrunk drugget and weigh 2·75 oz. each. A carrier is introduced into or removed from the circuit by a switch of the form shown, which is a modification of the receiver and transmitter patented by Sir C. W. Siemens in 1870. It consists of two short lengths of tube mounted on a rocking frame, so that either length may be interposed between the end faces of the main tube; one length is clear throughout, while the other, or receiving tube, has a bolt across it to

stop the carrier which can then be removed by swinging over the switch. The receiver is provided, moreover, with a glass door, through which the carrier may be seen, or removed should the switch be blocked through two carriers arriving together.

SIGNALLING.

756. Hand signal lamps. Presented by Messrs. J. Cowdy and Co., 1871. M.1232.

These are two examples of a one-handed signal lamp patented in 1868 by Messrs. W. A. Brown and R. L. Jones. The casing is cylindrical and has at the back a colza lamp with a concave reflector, and a flat glass in the door at the front. Between the oil lamp and the glass are three hinged "spectacle" frames connected with press knobs at the top, by depressing which, either of the coloured glasses fitted can be placed before the flame. The knobs are moved by the thumb, and springs are added, which, when a trigger at the top is released, cause the glasses to swing upward into the top portion of the casing. The japanned example is for railway use and the copper one for signalling at sea.

757. Electrical semaphore. Lent by H.M. Postmaster-General, 1888. M.2169.

This apparatus was brought out by Sir William Preece in 1862, and adopted on the London and South Western Railway. It is placed in the signalman's cabin to show him the position of a semaphore arm which may be invisible.

It consists of a miniature semaphore, the arm of which is raised by a rod attached to the armature of an electro-magnet whose circuit is closed by the actual semaphore.

758. Railway fog signaller. Lent by Messrs. Stanford and Co., 1898. M.3034.

This apparatus for placing detonating signals upon the metals when, through fog, the signal arms or lamps are invisible, was patented in 1892 by Messrs. B. S. Barton and E. K. Stanford.

The ordinary fog signal, which is shown in an adjacent case, consists of a metal box containing gunpowder and a few caps; to it is soldered a leaden band that can be folded under the head of the rail so as to prevent the box from falling off accidentally. During fog, a man stationed at the signal post fixes these detonators on the rail, or removes them, in accordance with the movements of the signal arm.

In the automatic apparatus, however, the detonators are secured to light carriers which fit on an arm that, by an independent rod from the signal cabin, can be swung horizontally in such a way as to place and retain the detonator on the rail. The detonators are stored in a star-shaped rotating hopper, from which they are fed one at a time and fixed on the placing arm by mechanism actuated by the cabin rod. A detonator that is withdrawn before being exploded is returned into the box, although not into the hopper. An electrical signalling arrangement is added which indicates when the detonator has been correctly placed on the rail. The cover of the iron box, in which the apparatus is contained, has been removed.

LAND TRANSPORT.—III.

Railway Vehicles and their Fittings, including Brakes, etc.

The passenger traffic which unexpectedly developed on the first railway was accommodated by placing coach bodies on wagon under-frames; and, following the stage coach arrangement, seats were booked before starting, luggage was carried on the top of the vehicle and frequently a guard was seated beside it outside. As traffic increased the form of passenger vehicle thus introduced was adhered to except that additional accommodation was obtained by providing more compartments in the greater length possible on a railway, and this is the construction still generally followed here; in America, however, the railway car appears to have been developed from the steamer saloon, and is characterised by the vestibule construction. In the stage coach traffic the inside passengers, representing the first-class, paid the highest fare, the outside passengers or second-class being taken at a reduced rate, while the poor could not avail themselves of the service. With the early railways first-class passengers were originally provided for, then a cheaper accommodation was added for the second, while the third-class, taken at a rate established by Parliament, were most unwillingly accommodated by the companies who, for many years, displayed considerable ingenuity in attempting to discourage cheap travelling. The earliest third-class vehicles consisted of open wagons without seats, and improvement was so slow that even in 1845 many coaches had neither windows nor lamps; about 1870, however, it began to be generally realised that it was upon the popular traffic that the receipts depended, the amount of dead weight carried and the capital invested in superior coaches being out of proportion to the paying load conveyed by them even at the higher rate charged. In carriage construction the increased length and capacity of the vehicles have been followed by the use of rolled steel beams in place of wood for the under-frames, and by the use of bogies instead of a long rigid wheel base. The buffers originally used were simply pads strengthened by metal bands, while the carriages were hooked together loosely like goods wagons, the present system of close coupling being introduced by Mr. Henry Booth, who, in 1836, patented the now general right and left threaded screw coupling; automatic couplings by which the vehicles of a train can be connected together or detached without a man having to pass between them have been very generally adopted in America and the matter is receiving much attention in England, where, however, the double buffers used in place of the American central buffer adds to the difficulty of the problem.

Railway Brakes.—For safely carrying traffic at a high speed the power of rapidly arresting the motion of a train is so essential that on almost all lines the early hand brakes, applied to a few vehicles only, have been replaced by those simultaneously applied

to all the wheels of the train so as to secure the maximum amount of retarding action. Chains or shafting have been used to transmit the power to these continuous brakes, but fluid pressure, chiefly air, is now the means generally employed; such brakes stop a train moving at 50 miles per hour within a distance of 1,000 to 1,500 ft., depending upon the state of the rails.

Rolling Stock.

759. Model of timber railway and quarry truck. (Scale 1 : 10.) Made in the Museum, 1904. Plate XI., No. 6. M.3359.

Lines of wooden rails, or "waggon ways," together with suitable trucks, appear to have been introduced about 1650 in the Newcastle colliery district, and in this connection it is recorded in the life of Lord Keeper North that in 1676 "the manner of the carriage is by laying rails of timber from the colliery down to the river exactly straight and parallel, and bulky carts are made with four rowlets fitting these rails, whereby the carriage is so easy that one horse will draw down four or five chaldrons of coals" (*i.e.*, 10·6 to 13·2 tons).

The models shown, however, were made from the drawings published by Desaguliers in 1734 as representing the arrangements used by Ralph Allen to convey stone from his quarries to the river Avon, near Bath, which are described as "a great improvement on some carriages and waggon-ways made use of at the coal mines near Newcastle." The quarries were situated 1·5 miles from the river and 500 ft. above its level, the line thus having an average gradient of 1 in 16.

The wagon-way consisted of rectangular rails of oak laid along the ground and probably connected by cross ties, covered with ballast to prevent damage from the horses' feet; the rails were 5 in. wide by 6 in. deep and were laid to an inside gauge of 3·75 ft.

The truck was carried on four cast-iron wheels having deep flanges on the inner edge to prevent them from leaving the rails, while the axles revolved in brass bearings secured to transverse beams below the floor; one wheel was fixed on each axle, the other being free to revolve independently. The loaded truck descended by gravitation and was controlled by a man walking behind it, who could retard the four wheels separately. This was accomplished at each rear wheel by a wooden brake block, pressed on to the rim by a lever which was drawn down by a chain wound on a drum, while the drum was rotated by a handspike and retained by a ratchet wheel; the front wheels were braked by actually locking them, two iron bolts being provided which could be thrust between their spokes by means of levers and rods operated from the rear of the truck.

The return journey was made by two horses, the brake levers being removed and placed inside the truck; the sides of the truck were also removable. The truck measured 12 ft. long by 3·5 ft. wide and had a wheel base of 6 ft. The wheels were 19 in. diam., 6·5 in. wide on the tread and had flanges 3 in. wide and 1 in. thick; the axles were 3 in. diam. The load carried was 4 tons, and the cost of each truck was £30.

760. Views on the Garnkirk and Glasgow Railway. Presented by R. B. Prosser, Esq., 1895, and C. E. & C. Stretton, Esqs., 1900. M.2755 and 3096.

This series of views was drawn by Mr. D. O. Hill, and published at Edinburgh in January, 1831.

The railway was intended as a mineral line and was 8·25 miles in length. George Stephenson was the engineer, and the line, which only cost £40,000, was opened for traffic in 1831. The Glasgow terminus was on the banks of the Forth and Clyde and Monkland canals, and is now the St. Rollox goods station, which is close to the Buchanan Street station of the Caledonian Railway, of whose system this line now forms part. The other terminus was at Cargill Colliery, near Gartsherrie Bridge, where the line joined the Monkland and Kirkintilloch Railway.

The locomotives shown in the views are the "St. Rollox," a four-wheeled engine, with inside cylinders 11 in. diam. by 16 in. stroke, and single drivers 4·5 ft. diam.; and the "George Stephenson," a four-coupled engine of the same dimensions, which opened the line. The carriages are chiefly open-topped four-wheeled wagons with hand rails. The road was laid with fish-bellied wrought iron rails on stone blocks.

761. Prints of early rolling stock of the Liverpool and Manchester Railway. Received 1895–6. M.2745.

These aquatints, published in 1833–4, record with considerable detail and accuracy the arrangement of our early trains.

The first-class carriages shown are obvious adaptations of the stage coach design, and have distinguishing names such as "Times," "Traveller," etc., just as when used on the road. The first-class train has a guard on the box-seat of the foremost coach, and another on a similar seat on the hindmost. Luggage is carried on the roofs, and an open truck is provided in which an ordinary private carriage is conveyed, with its occupants in it. The second-class carriages have low sides and a light awning supported considerably above them on uprights, while bench seats were fitted. The third-class carriages were simply open wagons without seats, but provided with holes in the floor to carry off the rain water that collected. Cattle, sheep and pigs are shown carried in trucks with open railed sides, those for sheep being two-storied; the horse truck closely resembles those still in use. The goods trucks are short four-wheeled vehicles without sides, while for conveying timber two trucks are used, the requisite length being obtained by leaving considerable space between the buffer-beams.

One of the engines shown is of the "Rocket" type, and is called the "North Star"; it had outside cylinders 11 in. diam. by 16 in. stroke with single drivers 60 in. diam. The tender is a four-wheeled truck, containing coal and a large water-barrel. The other engine, "Jupiter," was of the "Planet" class, with cylinders 11 in. diam. by 16 in. stroke, and 5 ft. drivers, but as it is shown with four equal wheels, it is probable that the engine represents one of the "Samson" class with cylinders 14 in. diam. by 16 in. stroke, and four coupled wheels 54 in. diam., but that the artist has omitted the coupling-rods. Its tender has a rectangular iron tank instead of the earlier wooden barrel.

762. Photographs of early railway carriages. Presented by the London and South Western Railway Co., 1896. M.2942.

These vehicles, which are still in existence, were used at the opening of the Bodmin and Wadebridge Railway, Cornwall, in 1834, and remained the only passenger carriages of the line till 1889, when the railway, which had remained isolated, was modernised.

The Bodmin and Wadebridge Railway was a mineral line, about 15 miles in total length and of standard gauge, built in 1834 as a private undertaking at a total cost of £35,000. It was financially unsuccessful and, although purchased by the London and South Western Railway in 1846, remained in its primitive state till 1889, when the Great Western connected with it at Bodmin; in 1896 the London and South Western joined it to their system at Wadebridge. Till its conversion to modern arrangements, the line was worked by two six-wheeled-coupled locomotives, one of which was in reserve, and a number of hopper wagons together with the four passenger vehicles shown in these views; the passenger traffic was, however, confined to the 7·5 miles of line between Bodmin and Wadebridge.

The composite carriage has a central first-class compartment and a second-class compartment at each end, all upholstered in blue cloth and lighted by two lamps in the roof, together with the side windows; each compartment is 4·5 ft. long, 6 ft. wide, and 5·75 ft. high, while the height from the rails to the top of the roof is 8·4 ft. The second-class carriage consists of one compartment, 10 ft. long, which seats sixteen persons, while the two third class carriages are open trucks with seats and side doors. The wheels are of cast iron 27 in. in diam. and support the vehicles by springs; spring draw-bars are fitted, but the buffers are formed of stuffed leather pads, or else of solid wood, and the coupling was performed by slack chains only.

In the frame is also a portion of an ordnance map showing the line, together with some other photographs of the rolling stock. Further particulars of the permanent way are given under No. 694.

763. Photograph of passenger carriage of 1838. Presented by the South Eastern Railway Co., 1894. M.2728.

This composite carriage was built in 1838, and used by the Duke of Wellington for his journeys on the Canterbury and Whitstable, now the South Eastern and Chatham Railway, while he held the position of Warden of the Cinque Ports. He was present at the opening of the Liverpool and Manchester line in 1830, and one of the first public men to appreciate fully the importance of steam locomotion.

In this carriage the central compartment is first class, the other two being second, and in the general arrangement some resemblance to a stage coach has been retained. The dimensions are: Length of body, 14·75 ft.; width of body outside, 6·7 ft.; length of wheel base, 8·125 ft.

764. Models of Indian railway carriages. (Scale 1 : 8.) Presented by the Bombay, Baroda and Central India Railway Co., 1883. M.2771.

These illustrate the third-class accommodation provided for the poorer natives of Hindostan; the carriages are double storied, and have four rows of longitudinal seats.

In the earlier type, access to the upper storey is gained by "monkey boards" at either end of the carriage, the four doors serving for both stories; ventilation is effected by louvres or sun blinds, and the accommodation is for 110 passengers. In the later type the upper storey is independent of the lower one, being reached by means of two doors and an internal stair in the centre and external stairs at either end of the carriage; ventilation is effected by wire gauze screens, and only eighty-eight passengers are carried. The gauge is 5·5 ft.; diam. of wheels 3·5 ft.; height above rail 13·1 ft., and the outside breadth of coaches 8·75 ft. The length of the earlier coach, over buffer beams, is 22 ft., and of the later 24·2 ft.; the wheel base of the former is 11 ft. and of the later 12 ft. The vehicles are built entirely of teak, with double roofs covered with painted canvas.

765. Models of cattle trucks. (Scales 1 : 6 and 1 : 12.) Presented by Alfred Welch, Esq., 1895. M.2764.

The larger scale model represents an ordinary narrow gauge cattle truck fitted with arrangements for refreshing the cattle *en route*, as introduced by Mr. Welch in 1869. Transverse sliding doors are also provided to separate the cattle or to permit the use of the truck, or a portion thereof, for merchandise. A rack is provided at one end of the truck for holding hay, which can be supplied through sliding doors; or the food may be placed in overhead racks supplied through similar doors on the roof, as shown at the other end of the model. For watering the cattle, troughs are provided outside the truck, so preserving an unobstructed interior. Lifting or turning covers fitted to these troughs prevent their being fouled when not in use. The drinking water is contained in an overhead cistern intended to be filled from the engine water crane, and small pipes are provided to distribute the water to the various troughs. After watering the cattle at a siding it is intended that any water remaining should be run off.

The two smaller scale complete models represent trucks intended for use on the broad gauge. The feeding and watering arrangements are similar to the above, but are arranged transversely at the ends or at the middle of the truck. The trucks are divided into separate stalls formed by sliding partitions. By the provision of double doors on each side, the cattle can be placed in, and removed from, their respective compartments without any "backing," a movement that is difficult of execution with frightened animals.

The partial model shows a modified form of sliding partition and double doors, arranged to dispense with "backing."

766. Model of cattle truck with radiating axles. (Scale 1:8.) Presented by J. Cleminson, Esq., 1880. M.1478.

This truck is fitted with the arrangement patented by Mr. Cleminson in 1876 for facilitating the passage of railway carriages round curves.

The truck has three axles, of which the middle one is capable of longitudinal movement, while the other two can swivel. The outer axles are so connected with the middle one that the sliding motion of th central axle causes the others to swivel and place themselves radial to the curve being traversed. The truck shown thus fitted has four compartments, each carrying three beasts for which troughs and racks are provided.

767. Model of double hopper coal wagon. (Scale 1: 16). Lent by Messrs. Sheffield and Twinberrow, 1905. M.3389.

This represents a large steel wagon of the form proposed and patented by Messrs. G. H. Sheffield and J. D. Twinberrow in 1898–9. The use of such wagons is estimated to increase the ratio of paying load to gross load and the earning power of a train of given weight by about 20 per cent., at the same time reducing the length of the train. There are, however, some objections to their general use, chiefly in connection with the handling of goods and the alteration required in terminal structures, but high capacity wagons of various types are now being used on several railways, especially for mineral traffic.

The wagon is formed as a double hopper with horizontal sliding doors and is carried on two four-wheeled bogies. The sides are in the form of deep plate girders with angle iron booms, tapered at the ends and attached to the headstocks. These serve as the main frames, being stiffened and tied together by the ends of the hoppers and also by transverse bulb bars at the top, while a stiff transom is built up over the centre of each bogie. There is also a hollow longitudinal tie which accommodates the draw bar. The hopper doors are mounted on rollers running on angles forming a light framework which supports the hand gearing for operating them. The bogies have pressed steel frames and wheels 3 ft. diam. with a wheel base of 5 ft., the axles being fitted with helical springs. They have no central pivot, but the load is carried by four semi-elliptic springs attached to the wagon body and bedded on bearing surfaces formed on the bogie frames. Their motion is controlled by four horizontal spring links, one at each corner, passing through lugs on the wagon and bogie frames. The buffers are arranged so as to equalise the pressures when passing round curves. The two stems pass through the headstock and are united by two cross beams, forming a frame which is pivoted just within the headstock; tension and compression springs are fitted to the inner cross beam and the two headstocks are connected by a draw-bar to which the compression springs are attached. The buffers are constructed to act as automatic couplings, each being provided with a pair of hinged arms which embrace the corresponding buffers of the next wagon. The arms have short backward extensions which are held outward by two lugs projecting from a central boss which is fixed to a movable spindle normally held by a spring so as to project from the face of the buffer and at the same time to release the arms. When one buffer head comes into contact with another, the arms embrace it, the spindle is pushed in and so locks them. The spindles can be rotated by a hand rod from either side to release the couplings.

The wagon is 42 ft. long, 8 ft. wide, and 9 ft. high, holds 36 tons of coal and has a tare weight of 14 tons; the load on each axle is 12·5 tons. The bogie centres are 32 ft. apart and the total wheel base is 37 ft.

Wagons of this form, holding 40 tons of coal, but without the automatic couplings, are in use on the North Eastern Railway.

768. Models of tramcars. (Scale 1: 24.) Presented by Z. Eastman, Esq., 1868. M.1059.

The two models show a form of street tramcar introduced by Mr. Eastman in 1864. The tramway required consists of two shallow

gutters in which the wheels run, thus resembling the early plateways and Train's tramway. The car wheels are without flanges, but have slightly rounded treads.

The axles are carried on central pins and races, so that they can swivel, and the axles, whether two or three in number, are connected together by cross bars or by segmental gear in such a way as to cause them to radiate horizontally when the horse pole is pulled sideways on passing a curve.

769. Model of locomotive frame fitted with radiating axles. (Scale 1: 4.) Contributed by W. B. Adams, Esq., 1869. M.1119.

This represents the underframe of a four-coupled tank engine having the leading and trailing axles fitted with the radiating arrangement patented by Mr. Adams in 1861, by which, when a curve is entered, the axle boxes, while sliding endways between the horn blocks, move the axles into a position that is approximately radial to the curve. This result is obtained by shaping the boxes and horn blocks to arcs of a circle; as, however, an inventor had in 1857 proposed a similar arrangement, but with the boxes held in straight guides, Mr. Adams prepared the two models in front of the case to show that the earlier scheme was unworkable. The engine represented would have a wheel base of 22 ft., and it was claimed that it would pass round a curve of 99 ft. radius.

The springs of the boxes of the driving wheels in the model are connected by equalising levers, by which the heavy load upon them, is equally distributed between the two wheels on each side, irrespective of the inequalities of the rails.

770. Models of carriage and wagon bogies. (Scale 1: 8.) Lent by the Leeds Forge Company, 1901. M.3200.

The employment of long railway carriages and waggons was only rendered possible by the adoption of the bogie truck, upon which the two ends of the vehicle are supported by swivel connections which reduce the rigid wheel base to that of the bogie so that it is even less than that of the short four-wheeled trucks formerly invariably used.

The models represent two modern bogies, manufactured upon the system patented by Mr. Samson Fox in 1885–96, in which the framework is made up of steel plate pressed, while hot, into trough-like forms, which give the desired strength and the means of attachment without the use of angle iron or much riveting. In this way it is stated that an underframe is made with one-fourth the number of pieces and one-third of the rivets that are required in a similar frame of the usual channel and angle iron construction; the consequent reduction in weight is such that coal waggons carrying 30 tons have been built of a tare weight of 12·8 tons.

The larger model represents a standard carriage bogie for a line of 5·5 ft. gauge. Each end of the carriage underframe is carried on a bolster, by a central swivel plate and side bearings; the bolster is supported by six helical springs, on a beam which is suspended from the bogie frame, so that it can swing transversely; the bogie frame itself is suspended from the axle boxes by plate springs and end washers of rubber.

The smaller model shows a waggon bogie for the standard gauge of 4·7 ft. Each end of the waggon underframe is supported by bearing plates on the side frames of the bogie, and by a central pivot fitting into a fixed plate on the transoms; the weight of the bogie is transmitted to the tops of the axle boxes by plate springs, whose ends are held by lugs fixed to the frames.

771. Early cast iron wagon wheel. Presented by H. G. the Duke of Rutland, K.G., 1904. M.3312.

The wheels of the wagons used on the early wooden railways were described in 1676 as "rowlets fitting the rails," and were probably double-flanged wooden wheels, but in 1734 wide single-flanged cast iron wheels were in use on a wooden railway near Bath. The example shown, however, is a narrow single-flanged cast iron wheel for running on metal rails, and is from the cast iron edge-rail line connecting Belvoir Castle with the Grantham Canal (*see* No. 679), where it was in use from 1793 to 1903.

The wheel is now 22·75 in. diam. and 3·5 in. wide on the tread, into which, however, a deep groove has been worn, partly owing to the very narrow face of the rails. It ran loose on the conical end of a fixed axle and was secured by a washer and split pin; the arms are curved so as to prevent fracture after casting.

772. Mansell's railway wheel. Contributed by the Commissioners of the Great Exhibition of 1851. M.140.

This construction of railway wheel, introduced in 1848 by Mr. R. C. Mansell, is now almost universally used for passenger carriages. The wheel consists of a rolled tire and a metal boss, but instead of spokes the wheel is made up of solid sections of hard wood with the grain arranged radially. At the centre the wood is held between flanges, and at the rim between two rings bolted together by through bolts. The tires are rolled with a groove on each side, and the rings have corresponding ridges formed on them, and in this way the tire is secured to the rest of the wheel. The great advantage of this method of attachment, which is also used for wheels with iron spokes, is that should the tire break, even in several places, the segments will still remain on the wheel, and thus the probability of derailment through a fractured tire is reduced. The wooden portion of the wheel has an important action in reducing the noise and jolting of the wheel, as it gives a certain amount of elasticity, and even where iron arms are used a wooden packing near the tire is sometimes introduced. The wooden sections are here shown dowelled together with metal plates, but these are now generally dispensed with.

773. Railway wheel with broken tire. Presented by R. Brotherhood, Esq., 1861. M.982.

This wheel, made by Mr. Brotherhood, has a wrought-iron boss, arms, and rim, with the usual flanged tire held continuously by securing rings as in No. 772. This tire has broken, but the tire fastening has retained it in place, although the wheel ran 115,000 miles after it had been fractured.

774. Oil axle-box. Contributed by D. Dietz, Esq., 1862. M.767.

This is a sectional example of an axle-box for railway carriages, patented by Mr. Dietz in 1860. The lower front portion of the box forms an oil reservoir, which is closed at the back by a partition and a half-collar which is forced upward against the journal by a spring. Any oil leaking past this partition collects on a saucer-shaped disc secured to the axle, and the edge of this disc is continuously wiped by a hinged finger which returns the oil on to the top of the bearing. The inner end of the box is closed by a millboard disc, to exclude dust.

775. Buffer for rolling stock. Contributed by Messrs. John Spencer and Sons, 1860. M.394.

This is a sectional example of a construction of spring buffer introduced by Messrs. Spencer and Corlett in 1854. The plunger is provided with a projecting collar at the back, which, by coming into contact with an internal projecting collar at the neck of the fixed casing, limits the forward travel. After the plunger has been placed in position the head is riveted to it; a volute spring is then inserted behind them in the casing and, while under compression, is fixed in position by a back cover secured by four interlocking lugs forming bayonet joints.

776. Railway buffer and drawing. Lent by Messrs. Ibbotson Bros. and Co., 1891. M.2366.

These show in section a modern buffer for absorbing the concussions on rolling stock. It consists of a solid steel head and plunger with a reduced tail, on which a flanged collar with an elliptical exterior can, by means of the special wrench shown, be screwed up solidly against the shoulder on the plunger. The plunger is carried in a casing bolted to the buffer beam, and encloses a volute spring under considerable compression. The base of the casing is formed by an iron plate with a central hole, through which the tail of the plunger passes, and is so kept in line. Messrs. Ibbotson's locking nuts (*see* No. 734) are employed on all the bolts shown.

777. Model of link and pin coupling. (Scale 1 : 8.) Lent by A. H. Higgins, Esq., 1900. M.3105.

This form of coupler was, until 1880, almost universally used for goods wagons in America, where central buffers are generally employed. Each buffer has a horizontal slot in its face, through which a long link is inserted and there secured by a vertical pin dropped in at the back of the buffer; the other end of this link is similarly secured by a pin behind the corresponding buffer. In coupling, the shunter had to remove the pin by hand and replace it after the link had been inserted, the whole operation being both difficult and dangerous.

778. Model of automatic coupling. (Scale 1 : 4). Presented by Louis Sterne, Esq., 1895. M.2736.

The model shows a pair of buffers fitted with a form of coupling introduced by Mr. Sterne about 1874. It is intended for vehicles with

a single central buffer, and is so constructed that the contact of the buffer secures the coupling together of the two trucks without other assistance.

The buffers are formed with a central cavity in which loosely fits a long link. At the back is a vertical pin which, when dropped as low as it will go, is passing through the long link, so closing the coupling. Before coupling together, the link is pinned into one of the buffers, while the other buffer has its pin supported by a horizontal roller so arranged that the link, when entering, pushes the roller away and is itself secured by the falling pin. When the pin is lifted for uncoupling, the roller by gravity returns to its supporting position.

779. Models of "Janney" couplings. (Scales 1 : 4 and 1 : 8.) Lent by F. J. S. Hopwood, Esq., C.B., C.M.G., 1900. M.3104.

In 1879 Mr. Eli Janney, of Pittsburg, U.S.A., patented a vertical plane car-coupler having a lateral moving knuckle; in 1887 the arrangement was accepted by the Master Car Builders' Association of America, with the result that the various modifications of the arrangement in use are classed as M.C.B. couplers. It was then adopted as the American standard goods coupling, and its use has since been greatly extended to rolling stock of all kinds.

The Janney coupling consists of a steel jaw fitted on one side with a knuckle or L-shaped lever turning on a vertical pin; this knuckle when being swung inward lifts a locking pin which subsequently drops and so prevents the return of the knuckle. An identical coupler is fitted to the end of the adjacent vehicle, and, so long as both or either of the knuckles are open when the vehicles come into contact, coupling will be effected; to uncouple, it is only necessary to raise either of the locking pins, by means of a chain or lever at the side of the vehicle. The knuckles have each a hole in them to permit of the use of the old link and pin coupler, when such a fitting is met with. At first, this coupling gave some trouble through the locking pins occasionally creeping upward, but in the larger model, which represents the later form, there is an automatic locking pawl that prevents this motion; owing, however, to the pawl being attached to the lifting shackle, it in no way interferes with the pin being raised when disconnecting.

Railway Brakes.

780. Models of a continuous brake. (Scales 1 : 4 and 1 : 8.) Presented by James Newall, Esq., 1862. M.841.

This is an early form of continuous brake, patented by Mr. Newall in 1852 and 1857; the smaller scale model alone need be described. Each vehicle of the train is provided with a brake gear, and also with a powerful helical steel spring by which the brake is applied. Running through the length of the train is a shaft connected between the carriages by universal joints, and this shaft can be rotated by a handwheel fixed in the guard's van, and which, by gearing, winds off the brakes, and compresses the helical springs throughout the train. The brake is held off by a ratchet in the guard's van, where also is a clutch by which the

gearing can be released and so the springs be allowed to act. A flexible cord runs the length of the train so that the brake can also be at once applied by the engine driver. While this brake embodies some features of modern appliances, it could never have been sufficiently powerful for the requirements of the present day.

781. Model of the Westinghouse brake. (Scale 1 : 4.) Made by the Westinghouse Brake Co., 1886. M.1637.

The Westinghouse continuous automatic pressure brake is, as its name implies, a brake that is applied to all the wheels throughout the train, and which, when through any accident the train is broken or the apparatus deranged, is automatically applied. The power by which this is effected is fluid pressure, the medium being compressed air stored at a pressure of 75 lbs. per sq. in. above that of the atmosphere.

The Westinghouse is the form of continuous brake most extensively adopted, although many other modifications have been introduced and are largely used. In a train so fitted the engine is provided with a vertical direct-acting air-pump driven by steam from the engine boiler. The air so compressed, after passing through a regulator valve under the control of the driver, enters a pipe which is continuous throughout the train, the connection between the carriages being made by flexible hose, with an interchangeable and readily made union. To the engine and beneath each carriage an air reservoir is fitted, and also a cylinder containing a single-acting piston, the piston rod of which is connected with the brake levers of each vehicle. The return stroke of this piston is caused by the action of a helical spring, which thus pulls the brakes off. Each air reservoir is fitted with a box containing a triple valve, which, when the pressure in the train pipe is reduced, opens a connection between the air reservoir and the brake cylinder, so that the compressed air can force out the pistons and so apply the brakes. If, therefore, a train should be divided through the failure of a draw bar or like accident, the air in the train pipe escapes, and the resulting fall in pressure at once applies the brakes throughout both portions of the train. On the engine and also on each guard's van is fitted a valve by which the air pressure in the train pipe may be lowered and so the brake be applied as required. These valves are so constructed that the application of the brakes may be rapid and powerful or only moderate, as the circumstances may demand. Gauges are fitted both on the engine and in the guards' vans by which the pressure of air in the apparatus may be observed. After a stop has been made the brakes remain on until the engine driver, by his large store of compressed air, restores the train pipe at once to full pressure.

The model shows a four-wheeled carriage frame fitted with the Westinghouse brake. The arrangement of brake levers is such that the four brake blocks to each pair of wheels are simultaneously applied, and with equal pressure, by the outward movement of the brake pistons. The brake reservoir and its triple valve are arranged near the side of the framing, and the engine reservoir with a hand air-pump are attached to the table on which the model is carried, and the driver's regulating valve on the right hand side. By the length of flexible tubing introduced, the model can run on the metals, and the brake be worked experimentally.

The large adjacent wall diagram shows the arrangement of the air pump, the driver's and the triple valve, together with the general arrangement of the brake cylinders and reservoirs.

782. Westinghouse brake gear in section. Made by the Westinghouse Brake Co., 1888. M.2255.

This is a full size example of the improved Westinghouse brake cylinder and reservoir, with the mechanism shown in section. It differs from the earlier pattern in that the reservoir is combined with the cylinder, so forming a more compact arrangement. The cylinder is at one end of the reservoir and the triple valve at the other. The air passed from the reservoir by the triple valve to the brake cylinder is conveyed by a steel tubing running the length af the reservoir.

783. Model of automatic vacuum brake. (Scale 1 : 4.) Lent by the Midland Railway Co., 1897. M.2984.

This shows a carriage underframe, with wheels, axle-boxes, etc., complete, fitted with the automatic vacuum continuous brake, in which there is a train pipe, with flexible connections and simple couplings, which communicates with the brake cylinder of each coach and is exhausted by a steam-jet apparatus on the engine. So long as the pressure in the pipes is below that of the atmosphere, the brake blocks remain off; but if, through the breakage of a pipe or the opening of a valve by a guard or driver, atmospheric air is allowed to enter, the whole of the brakes are applied with an effective pressure of about 12 lbs. per sq. in.

The brake cylinder, shown in section, is arranged vertically, and to save the height occupied by a connecting-rod is carried in trunnions as an oscillating cylinder; the piston is packed by a rolling ring of india-rubber. The upper face of the piston is open to the vacuum reservoir, while both faces are, by a valve box, placed in communication with the train pipe. The valve box, however, contains a small ball-valve which, on a sudden inrush of air, closes the entrance to the vacuum chamber, but permits the air to enter the space beneath the piston and so apply the brake. For shunting purposes a light wire is fitted by which the brake can be released from either side of the carriage.

LIFTING APPLIANCES.

Jacks, Winches, and Cranes.—For lifting heavy masses the two most elementary machines are the crowbar and the windlass. The crowbar, requiring no overhead structure, represents the type of machine most used for temporary or emergency work. The screw jack and the still more powerful hydraulic jack are most useful and convenient substitutes, and the greatest lifts yet performed have been made by large hydraulic rams.

The windlass, as represented by the cottage well-head gear, has developed into the more powerful winch, which, when provided with a head gear of its own, capable of swivelling, formed a crane

which again became a derrick when fitted with an arrangement for varying the radial distance of the load. The travelling crane is simply a winch carried on overhead rails upon which it can move and so convey its load, when raised, to any position within the enclosed area. The work entailed in lifting a load being so great, the time lost in doing the work by hand is serious, so that for most purposes power is employed. This is generally in the form of a simple high-pressure reversing steam engine, but frequently the power of engines employed for other work is conveyed to the winch either by shafting, or by a fly-rope, or now, very generally, by a cable delivering its current to an electric motor. In most lifting machines using chains or ropes some form of pulley-block is introduced to obtain a portion of the requisite mechanical advantage, and during recent years the improvements in the construction of flexible wire ropes have led to their extensive employment in this way in place of the more cumbersome and noisy chains so long in use.

For very many lifting machines the hydraulic system is adopted, the rams sometimes acting directly, but usually having their strokes multiplied by the reversed pulley block arrangement introduced by Lord Armstrong. The losses through friction in this machine increase with the extent to which the stroke is multiplied, hence the tendency in the manufacture of the more recent machines is to diminish this loss by reducing the multiplication and adopting long-stroke cylinders.

Lifts and Elevators.—The greater height of buildings, and the waste of power in raising the weight of the whole body when only a light weight is required to be conveyed to a higher storey, have led to the extensive use of passenger lifts, and of smaller ones for domestic use to be worked by hand. The passenger lift consists of a cage or small room controlled by vertical guides and capable of being lifted or lowered in a shaft or well-hole that passes up through the building. The power used is frequently that of a steam or gas engine, but, where obtainable, hydraulic power or electricity is more convenient. The weight of the empty cage is nearly counterbalanced by a weight so that the useful load alone is that upon which the work is done. For safety, some form of clutch gear is always fitted, which, should the lifting ropes fail, will at once seize the guides and retain the cage. A long direct-acting hydraulic ram, acting on the floor of the cage, is also frequently used instead of any overhead lifting rope, and, with a hydraulic balance, forms a most efficient and economical arrangement. Domestic lifts are usually small open-fronted boxes steadied by suitable wooden guides secured in the well-hole. A rope passes from the top of the cage up to an overhead V-grooved pulley and then down to a counterbalance weight sliding between the guides. Manual power is transmitted to the overhead pulley by an endless rope hanging from a large pulley on the main axle, but where the loads to be lifted are considerable, spur gearing is generally introduced to increase the mechanical advantage obtainable by the pulleys. A simple friction

brake is usually added, and in some cases the brake is applied automatically when the hand rope is left free. Water power and electricity from the public supply companies are also being used for working these small lifts.

A form of lifting appliance of very great capacity is represented by the ladder dredger (*see* Marine Engineering Section) in which a closed chain fitted with buckets travels continuously; the full ones being on one side and the returning empty ones on the other. For grain and similar materials such elevators are very convenient, and for lifts this device is also employed, but, owing to the continuous motion, the speed must be slow to permit of the load being placed on the platform or hooks.

Jacks, Winches and Cranes.

784. Screw jack. Received 1883. M.1675.

This is an ordinary "bottle" jack for lifting a load of 2 tons. It has a square threaded screw, 1·5 in. diam. and ·5 in. pitch, which can be turned by an iron lever inserted into either of the two transverse holes through it. The top of the screw is provided with a loose swivelling cap.

785. Traversing screw jacks. Contributed by G. England. Esq., 1869. M.1176-7.

These are respectively the original and a later form of the traversing screw-jack patented by Mr. England in 1839. The essential feature of the invention is the addition of a slide and a horizontal screw beneath an ordinary jack, by means of which the load, when raised, may be moved laterally.

In the earlier form the vertical screw is turned by a bar and the horizontal one by a ratchet lever; the screws have ordinary V-threads, though in the specification both screws are represented with square threads. In the later form (1869) the screws are square threaded, and both are provided with ratchet-braces.

Traversing jacks have since been very extensively used; nearly all locomotives carry them for use in replacing the engine should it become derailed.

786. Hydraulic jack. Made by Messrs. Tangyes, Limited. 1888. M.1676.

This is an improved form of the lifting jack patented by Messrs. James and Joseph Tangye in 1857, in which, by the combination of a small force pump and a hydraulic cylinder, great lifting power is obtained in a portable machine of considerable range.

The jack consists essentially of two steel castings, the upper one forming the hydraulic cylinder and containing also the force pump, while the lower one is the ram or plunger which terminates in a flat foot. The top of the cylinder casting forms the lifting head and also forms a reservoir or tank, while at the bottom is a projecting lip for

use when the head-room is insufficient for the insertion of the whole jack. The force pump is worked by a hand lever, and pumps water or some non-congealing fluid mixture from the reservoir into the hydraulic cylinder, thus lifting it; when lowering is to be performed, a small bye-pass valve projecting from the side of the cylinder is slightly opened, and this allows the fluid to pass back again into the reservoir.

The jack shown lifts 3 tons; it has a cylinder of 1·75 in. bore, while the ram of the small force pump is ·875 in. diam.

787. Haley's screw jack. Received 1883. M.1677.

This construction of jack was patented by Joseph Haley in 1840, and has been extensively used. The body is of timber plated with iron, and has a slot in it which serves as a guide to a vertical square-threaded screw, whose lower end is provided with a lifting claw, while the top has a swivel cap. The nut of the screw is formed into a worm wheel which engages a horizontal worm rotated by a double-ended winch handle. In the example shown, which is intended for a load of 2 tons, the hand moves through 805 times the distance travelled by the screw.

788. Hand winch (working). Presented by the Harrison Manufacturing Co., 1890. M.2350.

In this winch, which was patented by Mr. J. Harrison in 1889, the mechanical advantage is obtained by the use of epicyclic gearing. The shaft to which the winding drum is secured extends right through, and has a pinion of 12 teeth keyed to it. Loose on this shaft are a pinion of 11 teeth which by a clutch is held stationary, and the winch handle, the lever of which extends backward and carries a stud on which are two pinions cast together and free to turn, but having 11 and 12 teeth respectively; the one with 12 teeth gears with the dead wheel and that with 11 teeth gears with the wheel on the drum shaft, the result being that 6·2 turns of the handle are necessary to cause one revolution of the drum. The load will not run down when the handle is released, so that the winch is self-sustaining, but by lifting the catch which retains the dead wheel the drum is released. The example shown is for lifting a load of 3 cwt. directly from the barrel.

789. Model of a steam winch (working). (Scale 1 : 8.) Lent by W. Smith, Esq., 1862. M.331.

This compact arrangement of the directly-driven steam winding engine, now so extensively used on shipboard, etc., was patented and introduced in 1853 by Mr. J. Taylor, of Birkenhead.

Two inclined cylinders, at the ends of the framing, work upward upon disc cranks set at right angles on a shaft having a pinion on it which gears directly with the spur wheel on the barrel or winding shaft; a slower speed and greater purchase are also obtainable, by bringing into gear a second shaft which is, moreover, fitted with winch handles for use when steam is not available. The cylinders are fitted with link motions, simultaneously reversed by a single lever, and the drum is provided with a large band brake applied by a foot-lever, by which the lowering of a heavy load may be controlled.

At each end of the drum shaft are overhanging warping drums, round which it is usual to take one or two turns of a hauling rope, so as to be able to control the lifting or lowering by varying the tension on the slack end. By making these drums conical the rope continuously slips axially while being wound in, and thus avoids riding upon itself.

790. Model of a horizontal winding engine (working). (Scale 1 : 16.) Made about 1870. M.2558.

This represents a colliery winding engine. It has a pair of double-acting horizontal steam cylinders acting on a common crank-shaft, with overhanging cranks set at 90 deg. The winding drum is arranged for two ropes, one being let out as the other is drawn in, so that the weight of the cages is neutralised as well as that of a portion of the rope. To counterbalance the weight of the rope completely, however, a form of fusee is adopted—a spiral groove being cut on the conical faces of the winding drum, whereby the mechanical advantage of the machine increases when a great length of rope is down the mine, as then the radius of the drum is considerably reduced. After the spiral groove is filled the rope is wound on the parallel portion of the drum, but by suitably proportioning the spiral ends the correction obtained can be made as regular as would be the case with a spiral drum throughout. The spirals shown, however, give a much greater difference between the extreme diameters of the rope path than is usually required. In the middle of the drum is a brake strap connected with a lever which is actuated by a vertical steam cylinder of the trunk construction. Steam is supplied to this cylinder through a small slide valve under the immediate control of the engine driver. The supply of steam to the engines is regulated by a disc throttle valve, and reversing is performed by the shifting link motion. The three controlling handles are brought near together, so that the whole machine is perfectly under the control of one man. In these cylinders the piston rods are continued as tail rods through the back covers, the chief object of which arrangement is to remove the weight of the piston from the lower side of the cylinder, which otherwise would wear oval.

791. Model of winding engine and semi-portable boiler (working). (Scale 1 : 8.) Made by Messrs. Robey and Co., 1899. Plate XII., No. 1. M.3073.

This mining engine consists of a pair of horizontal cylinders arranged on a wrought iron girder frame, which also supports the multitubular boiler; one end of the frame forms a closed ash-pit, while the other supports the two steam cylinders, above which is a cradle carrying the smoke-box end of the boiler. The engine has link-motion reversing gear, a plunger feed-pump, and a strap-brake on the fly wheel.

One end of the crank-shaft carries a pinion gearing into a large spur wheel on an outside drum shaft, which is frequently fitted, as shown, with an overhanging crank for driving mine pumps when required. Running loose on this shaft are two winding drums, and between them is a pair of claw clutches, by which each can be thrown into or out of gear; each drum is fitted with a strap brake, so that either can lower its load by its brake, even while the other is winding.

792. Friction-driven hoist. Lent by Prof. H. S. Hele Shaw, 1885. M.1631.

This is an application, by Mr. Edward Shaw, of Prof. Hele Shaw's sphere and roller mechanism. When first introduced in 1884 this device was used on a calculating machine, but in the present example the variable velocity ratio is employed to control the motion of a friction-driven hoist.

The driving belt imparts motion to the pulleys, of which one is fast and the other loose. A disc with conical rim, acting as a friction-wheel, presses against and turns the sphere. Another disc, with rim similar to the first, is attached to the short drum, round which the lifting rope is coiled. The relative velocity and direction of the motion of the drum depend upon the position of the axis of rotation of the sphere. This axis may be changed instantaneously, and the direction of motion reversed, or the speed altered, by means of the handle which moves the pivoted frame above the sphere.

793. Model of hydraulic capstan. (Scale 1 : 4.) Lent by Messrs. Sir W. G. Armstrong, Whitworth and Co., 1899. M.3084.

This form of water pressure engine or hydraulic motor, for driving a capstan, was introduced in 1851 by Lord Armstrong; he had in 1848 patented a water motor with two diagonal cylinders acting on a single crank, and still earlier had constructed and tried with satisfactory results a rotary motor resembling the engine described in No. 88, but the three-cylinder engine shown is that which has been most extensively adopted.

The cylinders are single-acting and of the oscillating type, placed side by side, and working on a three-throw crank-shaft, which is connected with the capstan by spur and bevel gearing, having a ratio of 3 : 1, so arranged as to increase the hauling effort of the capstan. The cylinder trunnions are hollow and are provided with ports, so that by their oscillation they act as valves in admitting and discharging the driving fluid through corresponding ports formed in a hard metal ring in the bearings. This hydraulic engine is generally arranged below the surface, so as to be out of the way of those working the capstan; in many installations the engine bed is provided with trunnions, so that the whole arrangement can be turned over, to facilitate inspection or repairing of the working cylinders.

794. Model of jib crane. (Scale 1: 12.) Presented by Messrs. Bullivant and Co., 1902. M.3218.

This represents an early form of warehouse post crane, to be worked by manual power. It is constructed wholly of iron, and the post, jib and back stays are all forgings, held together by bolts. The post is capable of rotation on a footstep bearing in the basement, or on a lower floor, and a collar bearing at the working level, but no mechanism is provided for slewing, as this motion can be performed directly. The lifting gear is attached to the post and can be made single or double purchase at will, by sliding the pinion shaft; the total ratio of the spur gear is 1 : 23. The second motion shaft is provided with an iron band brake for use in sustaining or lowering a load.

795. Model of hydraulic crane. (Scale ·1 : 12.) Lent by Messrs. Sir W. G. Armstrong, Whitworth and Co., 1899. Plate XII., No. 2. M.3082.

This closely resembles the crane erected at Newcastle quay in 1846 by Lord Armstrong, when he patented and first introduced his system of hydraulic machinery; its success was such that complete installations of hydraulic lifting appliances were soon erected by him at Grimsby, Liverpool, and elsewhere. The leading feature of the crane is that the comparatively short stroke of a hydraulic cylinder is multiplied, by causing it to move the block of a pulley tackle, so that an ample range of lift, together with high lifting speed are secured.

The early crane represented has a hydraulic cylinder fitted with a pulling piston, the rod of which carries a sheave and also the end of the lifting chain, by which arrangement, together with an external fixed pulley, the lift of the crane is made equal to three times the travel of the piston. The cylinder is arranged underground at a slope of 1 in 27, so that gravity assists in running out the chain; friction is reduced also by roller guides supporting the crosshead. For use in slewing, the crane is provided at the base of the post with a spur wheel, into which gears a rack attached to the piston of a small horizontal double-acting hydraulic cylinder. The lifting and slewing are controlled by slide valves worked by hand levers, and the crane hook is provided with a weight sufficient to keep the chain tight during the return stroke of the lifting piston.

796. Model of a weighing crane. (Scale 1 : 8.) Contributed by the Kirkstall Forge Co., 1860. M.333

The adaptation of a crane to the further purpose of weighing the load lifted has been accomplished, either by measuring the pull on the chain, usually by some form of suspended weighing machine, or else, as in this example, by directly measuring the increase in weight of the whole crane due to the load lifted. This latter method was patented as early as 1837 by Messrs. Hitchin and Oram, but the construction here shown was extensively introduced in France by M. M. George about 1844, and in England by Mr. J. O. Butler in 1858.

The crane is of the jib type, worked by hand power, and has single and double purchase gear, convertible by sliding the winch handle shaft; there is a band brake on the second motion shaft, and a ratchet wheel for a retaining pawl on the chain drum, the surface of which has a helical groove to ensure smooth winding of the chain. The crane is carried on a circular table, which has projecting from its lower surface a crane post resting in a footstep at the bottom of the foundation and supported by a socket in the upper foundation plate. This plate is formed with an internal spur ring with which engages a pinion carried on a vertical shaft by which the crane is slewed.

The modification in the crane, by which the weighing is performed, consists in connecting the jib, the gearing and its brackets into one rigid frame, which is attached to the remainder of the structure by links and knife edges. Outside the gear framing are two standards secured to the revolving platform, and to these the framing is tied on each side by an upper and lower horizontal link connecting knife edges; in this way the overturning moment of the crane is neutralised by a pair of horizontal forces, or a "couple," while the downward force, representing the

weight of this portion of the crane together with its load, is unaffected. This downward force, which resembles the shearing force in a girder, is resisted by a lever turning on a fulcrum attached to the platform and pressing on a knife edge under the jib frame, while the other extremity is provided with a heavy scale-pan and movable weight; the pan balances the weight of the crane, so that proportionate weights placed in the pan will give the weight of the load.

Except when weighing has to be done, the crane brackets are lowered on to the main platform and the knife edges thrown out of action by a cam, which lifts the scale beam and locks it.

797. Crane with automatic balance. (Scale 1 : 16.) Lent by Robert Pirie, Esq., 1896. M.2958.

This construction of automatic balanced crane was patented by Mr. Pirie in 1885.

It is of the jib type, but has a projecting bracket behind that forms a pair of curved rails, on which run flanged wheels connected with a counter-balance weight. The crane hook terminates in a sheave round which passes a lifting rope; one end of this rope is attached to the winding drum of an ordinary hand gear, while the other end goes round the sheaves of a hydraulic ram and cylinder, and is then made fast to the framing. From the lifting rope also extend two light ropes which, after passing over sheaves on the ail bracket, are attached to the balance weight. The hydraulic cylinder has a bye pass, and when a load is to be lifted the increasing tension on the lifting rope slowly passes the water from the cylinder, thus allowing the balance-weight to be pulled up the inclined guides. The framing is carried on a central post, on which, at the base, the frame can slightly rock; when the balance-weight has moved out far enough the slight rock backward moves a wedge that closes the bye-pass valve of the hydraulic cylinder, and so prevents further movement of the counterbalance.

The crane, being completely in balance, requires no holding down, and in the model is shown carried on four columns with rails running between.

798. Model of travelling crane. (Scale 1 : 4.) Received 1877. M.2528.

This shows a form of "accident" or "breakdown" crane for use in clearing an obstructed portion of a railway; in its general arrangement, however, it resembles a crane built in 1806 by Mr. Peter Kier for the Ramsgate harbour works.

A four-wheeled truck, of standard gauge and fitted with brakes, supports the crane post and a roller path; and the whole of the frame, including the post and jib, are of timber. The jib is capable of making a complete turn, while a backward extension of it carries a platform for the men working the crane, and also two rails along which a counter-balance weight, mounted on wheels, can be traversed by a small winch, so that its leverage can be increased when a heavy load is being lifted. The load is raised by a double-purchase winch worked by two men; the slewing is done directly without the aid of mechanism and, as the counter-weight turns with the jib, the balance, once established, remains undisturbed.

The radius of the jib circle is 11·5 ft.; the wheel base is 5 ft.; the counterbalance weighs ·5 ton, and the maximum load that can be lifted is 2 tons.

799. Model of a travelling crane. (Scale 1 : 15.) Presented by Capt. F. Fowke, R.E., 1859. M.1761.

This represents a travelling gantry employed by M. M. Nepveu and Cie., for the temporary work of erecting machinery in the Paris Exhibition of 1855. The four wheels upon which it runs are free to turn like ordinary castors, so that it can be moved in any direction on a flat floor.

800. Model of traversing sheer legs. (Scale 1 : 24.) Presented by Messrs. Day and Summers, 1868. Plate XII., No. 4. M.1064.

Sheer legs consist of two nearly vertical masts lashed together at the top, and there supporting a pulley tackle. This arrangement is free to swing to and fro, but its motion is restricted by guy ropes, so that by manipulating these ropes a load, while lifted by the legs, can be traversed horizontally. For erecting masts in a ship, the sheer legs used are generally built on a dismantled hull known as a sheer-hulk. When a third leg is added, the arrangement becomes a tripod, which is much more secure, but less convenient, as it is almost useless for traversing a load.

In 1862, however, Messrs. C. A. Day and T. Summers patented a tripod in which the back leg was capable of being traversed in a guide by mechanical means, and the model generally represents the first traversing sheer legs constructed, which was erected by them at Southampton in 1863.

The legs are built of ·5 in. plate, with double-riveted butt joints circumferentially and single-riveted longitudinal joints. The front legs are of 110 ft. effective length, 20 in. diam., at the ends, and 40 in. diam. at the middle, and the back leg is 138·5 ft. long. The latter has its lower end secured to a nut, travelling in horizontal guides and moved by a screw, 8·5 in. diam. and 48·25 ft. long, which is rotated through gearing by a pair of high-pressure steam cylinders 12 in. diam. by 15 in. stroke. The total traverse for a load is 47 ft., of which 32 ft. are beyond the quay wall. The engine also drives a shaft parallel with the screw, which gives motion to a hoisting winch at the other end of the bedplate. There is a three-sheaved pulley-block for heavy lifts and a single sheaved block, or " whip," for light loads. The proof load of the structure was 100 tons. On the model are given particulars of many other sheer legs of this type.

801. Model of hydraulic sheer legs. (Scale 1 : 25.) Made by Mons. P. Regnard, 1899. Plate XII., No. 3. M.3060.

This lifting appliance was designed and constructed by the Compagnie de Fives-Lille, in 1887, for the Port of Marseilles.

The equal legs are built-up box girders 3·28 ft. sq. at the middle, tapering to 1·64 ft. sq. at the ends; the effective length of each is over 110 ft. The back leg is similarly constructed, but its lower end is

carried in guides, inclined at 53 deg., with the horizontal, formed on two large plate-frames, built in the engine-house and bolted down to a concrete foundation. Between these guides is a crosshead connected, by a piston-rod 7·48 in. diam., with the piston of a hydraulic cylinder 21 in. diam. and 22·7 ft. stroke, by which the heel of the back leg is controlled. By the movement thus permitted a horizontal travel of the load through a distance of 46 ft. is obtainable; the maximum overhang from the quay wall is 30 ft.

The load is lifted by a direct-acting hydraulic cylinder, 21 in. diam., with a piston-rod 7·5 in. diam., and a stroke of 43 ft. This cylinder is hung by two side rods, in order that the weight of the load shall not be taken by the metal of the cylinder; a safety device is also provided consisting of two racks attached to the piston-rod crosshead and fitting in stirrup-shaped pawls fixed to the cylinder. The mechanism for moving the back leg is similarly fitted with safety racks. On the back leg is placed a small hydraulic cylinder multiplying eight times and giving a travel of 46 ft. for use in lifting slings and other light loads not exceeding 8 tons; the fixed end of the chain from this jigger is secured to a double-geared winch, by which arrangement the position of the lifting hook can be quickly adjusted.

Water, at 710 lbs. pressure, is supplied by the accumulator shown, which is fed by a direct-acting pumping-engine and controlled by valves in the engine house, but the lifting is controlled from an elevated platform; the water connections with the hydraulic cylinders are made by swivelling pipes, which, with the rest of the service, are 2·95 in. diam. With the accumulator pressure, the maximum load that can be lifted is 75 tons. For greater loads this pressure is intensified by the horizontal direct-acting hydraulic pumps shown, which have pistons 13·19 in. and 9·84 in. diam. respectively, with a stroke of 3·28 ft. and a common trunk 9·56 in. diam.; by these a pressure is obtained sufficient for lifting the maximum load of 120 tons, while on test a load of 140 tons was dealt with. This arrangement is also reversible, so as to economise accumulator water when lifting loads of less than 25 tons.

The leading dimensions of the structure are:—Height of lift, 46 ft.; height of lift above quay, 22·9 ft.; lateral spread of front legs, 36 ft.; distance of heel of legs from edge of quay, 3·9 ft.; effective length of front legs, 110·5 ft.; effective length of back leg, 109·9 ft.; horizontal travel of apex, 46 ft.; volume of water used in a lift of 46 ft., 112 cub. ft.; volume of water used in traversing through 46 ft., 55 cub. ft.; test load, 140 tons.

802. Model of 50-ton floating crane. (Scale 1: 24.) Lent by Messrs. Hunter and English, 1896. Plate XII., No. 5.

M.2964.

This crane, constructed in 1885 on a system patented by Mr. Walter Hunter, is employed at the Tilbury Docks in performing similar lifting work to that done by sheer legs, but without being stationary or requiring that the loads be brought to it.

The crane itself rests upon steel rollers running upon a curb, 26 ft. diam., supported on a wrought iron cylinder, built into the supporting hull and secured by bulkheads to its sides; the centre of the crane is over the centre of the hull. The jib consists of two tubular steel

members, and the framing of the crane is of wrought iron; it contains at the back a chamber holding cast iron kentledge blocks that counterbalance the weight of the overhanging jib. The load being lifted is counterbalanced, so as to keep the hull level, by a weighted wrought-iron truck weighing 130 tons and running upon rails along which it is traversed by power. When a load to be lifted is properly slung the lifting engines are run until a slight list is given to the hull, the balance weight is then moved out until the hull is again level; the lifting can then be proceeded with, and any slewing done without disturbing the even trim of the hull.

The lifting engine consists of a pair of horizontal 12 in. by 12 in. cylinders, and drives a 36 in. diam. hoisting barrel by worm gear. The steel rope is 6 in. circumference, and the moving block has in it three sheaves 36 in. diam. The lifting engine also slews the crane, by friction clutches and spur gear, that drive a pinion engaging in a fixed circular rack 14·6 ft. diam. The balance truck is moved to and from the centre by two long screws, which are driven by bevel gear from a small Willans' three-cylinder engine.

The vessel is propelled by twin screws 5 ft. diam. by 6·5 ft. pitch, driven by two compound engines with 9 in. and 18 in. cylinders by 18 in. stroke, indicating collectively 160 H.P., and giving a speed of four knots.

Steam for all purposes is supplied from a return tube multitubular boiler 8 ft. diam., by 8·6 ft. long, with 78 tubes 3 in. diam. To the engines on the crane the steam is conveyed by a swivel pipe in the crane centre, and the exhaust is led through an annular pipe to the surface condenser, which has independent air and circulating pumps.

The leading dimensions of the crane are:—Length of hull, 110 ft.; breadth, 44 ft.; depth, 9 ft.; height of deck above water level, 3·5 ft.; radius of lift, 47 ft.; length of jib between centres, 91 ft.; effective lift from water level, 70 ft.

803. Model of travelling steam crane. (Scale 1 : 8.) Lent by Messrs. Joseph Booth and Bros., 1900. M.3129.

This type of crane travels on ordinary rails and is capable of lifting and carrying loads of from 1 to 5 tons without any holding down, the weight of the boiler, etc., sufficiently counterbalancing the load; the model represents a 3-ton crane for travelling on rails of the standard gauge.

The power is exerted by two vertical steam cylinders, fitted with link motion reversing gear, which drive a horizontal crank-shaft provided with clutches and gearing by which the power can be transmitted to the various mechanisms for travelling, slewing, raising the jib, and lifting the load. The crane base is a four-wheeled truck carrying a circular race upon which the weight of the machinery and load is supported by three rollers, while the interior of the race forms the spur ring that is utilised when slewing.

804. Photographs of steam cranes. Presented by T. Smith, Esq., 1892. M.2452.

The travelling crane, for lifting weights up to 16 tons, runs on the ordinary permanent way and fits other rolling stock. The engine has two double-acting cylinders, from which by clutches and gearing all

movements of the crane can be obtained. The large chain barrel gives a great range of lift, and the curved form of the braced jib adds to the available height above the rails.

The travelling crane for ship-yards is intended for lifting a load of 10 tons at a radius of 20 ft., or 7 tons at 25 ft. from the centre post, the radius being variable. It is propelled and all other motions are given by two cylinders 8·5 in. diam. by 12 in. stroke, receiving their steam from a Nicholson boiler 8 ft. high by 4·5 ft. diam. The form of trussed jib gives the headroom of the curved type while directly meeting the stresses. The total weight of the machine is 50 tons, and it hoists by a steel wire rope 1·125 in. diam.

The overhead travelling crane has a span of 50 ft., and will lift a weight of 75 tons through a height of 30 ft. without the lifting rope overlapping. Steam at 80 lbs. pressure is supplied by a 9 ft. by 4·5 ft. diam., boiler, overhanging the crab on one side, and partly counterbalanced by the water tank on the other. The engine has a pair of diagonal steam cylinders 9·5 in. diam. by 14 in. stroke, and is connected for the various motions by double cone friction clutches; the motion to the longitudinal travelling wheels being transmitted through a square shaft. The steel wire lifting rope is 6 in. circumference, and runs in four plies round grooved sheaves in the top and bottom blocks, but the gearing is arranged to give three different speeds for hoisting.

805. Model of combined crane and locomotive. (Scale 1 : 8.) Received 1896. Plate XII., No. 6. M.2950.

The locomotive is a small four-wheeled coupled tank engine with outside cylinders and Joy's valve gear. The tanks and coal bunkers are at the sides; there is a screw brake, and the buffer beam is fitted with large heads so as to suit a variety of trollies and trucks.

The crane consists of a single jib carried on a swinging fulcrum, having its inner end controlled by guides secured to a top ring that is supported on an upward extension of the circular external firebox. The end of the jib is pulled downward by the piston rod of a vertical direct-acting steam cylinder, the motion of which is thus magnified. The jib has three hooks to it, for dealing with loads of 2, 3, or 4 tons at distances from the centre of the railway of 20, 16 and 12 ft. respectively; the weight of the jib and part of the load are balanced by a counter-weight attached to the top ring. The load is slewed by a three-cylinder engine, which, by worm and spur gearing, rotates the top ring that carries the jib, etc.

806. Model of block setting "Titan." (Scale 1 : 24.) Lent by Messrs. Stothert and Pitt, Ltd., 1905. M.3404.

This represents a crane designed by Mr. W. Matthews and constructed by Messrs. Stothert and Pitt in 1891, for use in setting the concrete blocks composing the piers of the Admiralty Harbour, Peterhead, Scotland. It lifts a maximum load of 50 tons, at a radius of 100 feet. Such cranes were introduced about 1869, and they have since been developed to the form shown. They are designed to set all the blocks in advance of the machine, which itself rests on the finished portion of the work, thus dispensing with staging.

The structure consists of two counterbalanced cantilevers 160 ft. long with 82·75 ft. overhang, placed 9 ft. apart and built as box girders,

11 ft. deep at the centre, tapering to 4 ft. at the front ends. These are braced together at the centre and ends only, and form the jib along which travels an eight-wheeled truck or "jenny" carrying the load. The tail end of the jib supports the driving machinery and ballast tanks. The cantilevers rest on, and are rigidly braced to, a circular box-girder ring which is supported by 52 conical rollers resting on a lower ring which forms part of the truck or running carriage. The crane runs on two tracks 31 ft. apart, one being of the standard gauge laid on the road, and the other of 3·17 ft. gauge placed on the parapet about 11 ft. higher. The high side of the truck is built as a lattice girder and the lower side as a single box-girder, while across these are placed four box-girders which support the lower rolling ring. The truck is mounted on 32 wheels spread over a wheel base of 34·5 ft. and the journals are fitted with springs. The jib is secured by a central pivot and is slewed by a large toothed ring; large hook brackets are provided for safety, but the centre of gravity of the whole superstructure always falls within the roller path.

The load is lifted by an eight part steel wire rope which is reeved double in two parallel portions, so that two parts are coiled round the barrel, and there is an equalising pulley at the end of the cantilevers. The blocks are attached by two lewis-bars having hinged loops at their upper ends which hook over the ends of a swivelling cross beam attached to the pulley block. The lifting drum is 8·5 ft. diam. and is provided with brakes for lowering; the racking and slewing motions are worked from shafting, and a vertical shaft, passing through the centre pin, drives the running wheels by pitch chains and gearing. Steam is supplied at 70 lbs. pressure by a vertical boiler to a pair of engines having cylinders 12 in. diam. by 19 in. stroke, which actuate the whole of the motions.

The crane weighs about 350 tons and its test load was 62·5 tons.

Lifts and Elevators.

807. Model of a continuous elevator. (Scale 1 : 8.) Contributed by the Commissioners of the Great Exhibition, 1851. M.509.

This endless chain elevator was patented by Mr. John Spurgin in 1837, and is intended for lifting bricks and mortar to the top of a building in course of construction. The top drum has the shaft prolonged for the purpose of driving. Studs, to which buckets were attached, project from the chain.

808. Model of a power lift. (Scale 1 : 8.) Presented by the Rev. Dan Greatorex, B.D., 1895. M.2737.

This model shows a form of lift introduced by the donor in 1851. It is designed for working by hand or from running shafting, and is shown arranged in a building of three floors, the detailed construction of which is represented, as well as the method of forming the well-hole, through which the cage of the lift works.

The cage is guided by four vertical timber guides, and is supported by two ropes, attached to a wrought iron forging, from which four tie rods descend to the floor of the cage. The ropes pass over two V-grooved pulleys overhead, and then connect with a pair of balance-

weights which work in guides at the back of the well-hole. Three lifting ropes have been provided for, but the central one has probably never been fitted.

When working by hand power, the operator pulls at one side of an endless rope passing over a large V-grooved pulley on a shaft of the overhead gear; on this shaft is a pinion, gearing with a large spur wheel on the main shaft. For more quickly lifting light loads, a second wheel and pinion of less ratio are introduced, and a claw clutch, which can be operated by a vertical rod that passes through all the floors, enables this change gear to be operated from any level.

For driving by power, a single belt pulley loose on the counter-shaft is provided, which can be thrown in by a clutch similarly controlled; the lowering is performed by gravity under the control of a strap brake arranged on the main shaft. This brake is operated by a vertical rod on the right hand side, controlled by hand wheels on every floor, or by an endless rope that passes through the cage.

809. Model of automatic tipping lift. (Scale 1 : 12.) Lent by H. F. Donaldson, Esq., 1896. M.2954.

This lift, patented in 1895 by Mr. Donaldson, is used at the cold storage depot at West Smithfield for taking frozen meat from a receiving staging and delivering it on any of the five floors of the building. The two lifts there fitted are worked by hydraulic rams, and were constructed by Sir W. G. Armstrong, Mitchell and Co.; each is capable of lifting thirty carcases to a height of 50 ft. in one minute.

The method of working is as follows:—The carcases having been stacked upon the platform or tray, the attendant pulls over the lever controlling the points of the floor at which the meat is to be delivered. When these set points are reached, the platform tips and stops automatically; the carcases then slide on to a shoot that delivers them to other inclined shoots leading directly into the chambers.

810. Diagrams of hydraulic lifts. Lent by E. B. Ellington, Esq., 1891. M.2384.

Hydraulic lift balance:—In a long-stroke direct-acting hydraulic lift the size of the ram is determined entirely by its stability as a column, so that unless overhead pulleys and counterbalancing weights and chains are introduced, the consumption of high-pressure water by such lifts becomes prohibitive. The hydraulic balance invented by Mr. Ellington, however, counterbalances the weight of the cage and the ram, and thus reduces the consumption of water to that necessitated solely by the capacity and speed of the lift. This is effected by placing the water in the lift cylinder in direct communication with that in a weighted hydraulic cylinder of moderate stroke, so loaded that the permanent weight of the cage and its ram is balanced to the required degree; this water, however, merely acts as a fluid connection between the two cylinders, and is not consumed. To cause the lift to ascend, the load on the hydraulic cylinder is increased by the downward pressure of a ram under the action of water from the power mains, the water used in giving this added pressure representing the consumption in the upward travel of the cage.

In another arrangement represented, the counterbalance load is put

on by low pressure water from an elevated tank, so that as the lift ram goes up the increased load due to its lost displacement, or flotation, may be partly compensated for by a greater head on the balance ram.

Suspended lift :—This is worked by a long-stroke vertical hydraulic cylinder with a differential ram, the portion passing through the upper part of the cylinder being 2·5 in. diam., while the lower one is 6 in. In this way, long-stroke rams of sufficient stability can be economically employed, whatever the water pressure, since the effective area is only an annulus ; the weight of the cage is counterbalanced by that of the ram, assisted by added weights if necessary.

811. Model of a hydraulic balanced lift (working). Lent by Messrs. R. Waygood and Co., 1891. M.2368.

This represents a direct-acting hydraulic lift, in which the weight of the cage and ram is balanced by an arrangement known as the hydraulic balance, by which the use of overhead chains and attachments is avoided.

The cage is guided in its course by two circular wrought-iron guides, and the weight is borne by a solid steel ram built up in lengths by screwed joints. The ram works in a vertical cylinder sunk in the ground and fitted at the top with the usual stuffing-box and packing. The upper part of the cylinder communicates with the cylinder of the hydraulic balance, which consists, in this example, of a lower cylinder fitted with a ram, from the top of which projects a flange, from which two tie-rods descend to a heavy balance weight below, so that the pressure on the ram supports these weights, and this pressure is nearly equivalent to the hydraulic pressure of the cage and ram.

Inside the ram of the balance fits a smaller stationary ram, so that when water under pressure is admitted to this ram its effect is to increase the pressure on the water in the hydraulic balance, and so force up the cage and its load. The water connecting the balance with the cage simply passes backwards and forwards when the machine is being worked, the water actually used being that which enters the upper ram of the balance. The water, in the model, is supplied by a hand force pump, fitted with a safety and relief valve, but in practice it would be supplied from an independent accumulator, or from a public supply of water, preferably at high pressure. The balance cylinder may be used as an accumulator, and some of its water be employed as pressure water by letting it into the upper ram.

812. Model of hydraulic lift (working). (Scale about 1 : 8.) Lent by the Hydraulic Engineering Co., Ltd., 1904. M.3356.

This represents a simple direct acting hydraulic lift in which the weight of the cage and its load are overcome by the pressure of water exerted upon a ram working in a vertical cylinder arranged at the bottom of the well-hole, the stroke of the ram being equal to the total lift required.

The cage is guided by two circular steel rods secured to the lift shaft near opposite corners, and the ram, which is built up of steel rods screwed together, is attached beneath the floor of the cage by a ram-head which distributes the effort. The cylinder of the ram is in

lengths connected together by flange joints and is accommodated in a bore-hole sunk below the lift shaft. The top of the cylinder has usually a gland packing, and at its sides are spring buffers to absorb the shock should the lift be lowered too rapidly at the end of its travel.

The admission and discharge of the water are controlled by a valve actuated by the attendant in the cage through a rope, but in the model special arrangements are introduced for the purpose of insuring that the lift shall not be started before the doors are closed and that no door leading into the well-hole shall be open except that at which the lift is standing ; also to give automatic stopping. The valve is actuated by a triple vertical rod, one member of which passes through the cage, to be operated by hand, another beside it, and the third outside the shaft. The doors are locked by bolts which are withdrawn by the cage as it comes opposite them, and each is also provided near its hinge with a small curved arm which, when the door is opened, enters a notch in the front valve-rod and thereby secures it. The other valve-rod is provided at intervals with special projections, by which the lift may be automatically stopped at any intended floor.

The water, in the model, is supplied by a hand pump, but in an actual lift would be obtained from an accumulator or from the mains, while a hydraulic balance would usually be interposed to compensate for the absence of counter-weights.

TRANSMISSION OF POWER.

Until the introduction of the rotative steam engine, towards the close of the last century, the prime movers available were of such limited capacity that any considerable sub-division of their power was unnecessary. Hand power was applied directly, and power obtained by wind and water wheels was usually transmitted by wooden shafts and toothed gearing to the adjacent simple machines to be driven. But with the growth of machines for the performance of much of the more monotonous part of human labour, the distribution of the power obtained by the various engines employed became of increased importance.

Shafting.—The early wooden shafts were replaced by cast iron usually of square section, so as to facilitate the securing of the pulleys by "staking on." Later on these were supplanted by wrought iron, and now steel is the material employed. By the use of the stronger metal and by running at far higher speeds, the lighter and more efficient type now employed was arrived at. For connecting shafting when not in line, spur gearing was usually employed, but with higher speeds belting was found quieter and more convenient. Ropes and pitch chains are now being extensively used, although there has recently been a considerable revival of spur gearing for many conditions, and when well made it is probably more efficient than belting. Considerable reduction in weight has been attained by the substitution of wrought iron for cast iron in the construction of pulleys, and, while leather as a material for belting is proverbially hard to beat, its high cost has led to the employment of belts woven from cotton combined with india-rubber.

Fly-Ropes.—For long distances a small rope of cotton or wire running at a speed of about 5,000 ft. per min. transmits a great amount of power very quietly and efficiently, but when the distance is to be measured in miles, the losses in friction at the relay stations reduce the efficiency considerably, and render the plan inferior to the electric methods in which the chief losses are usually confined to the two ends of the installation.

Fluid Pressure.—As two gallons of water per min., delivered under a pressure of 700 lbs. per sq. in., is equal to 1 H.P., it is not surprising that power can be very effectively transmitted in this way. Where the work is of a kind that suits the present forms of water motor, or is intermittent as with lifting appliances, the convenience and efficiency of the method has led to its very extensive adoption, and the success of the companies for the public supply of energy in this form has largely extended the use of lifting appliances for general purposes. The method, however, dates from 1846 when Lord Armstrong constructed the first multiplying hydraulic crane at Newcastle quay, and then introduced a complete system of such cranes at Grimsby docks.

William Murdock transmitted power by compressed air at Soho, and the method has since been extensively adopted, particularly in mines where the exhaust air from the motors is of value in improving the defective ventilation. The efficiency otherwise is seriously reduced owing to the unavoidable losses through thermal changes during compression and expansion which increase rapidly with the pressures employed.

Electricity.—For the continuous transmission of power over long distances electricity is at present the most economical agent, and there are evidences that for much shorter lengths the same method will be still more employed. To save copper, the potentials used for long transmissions have been of fatal intensity, but where the distance is not great there is no sufficient reason for introducing such pressures, and for ready adaptability there is no medium for conveying energy so flexible or so readily laid as an electric conductor. The economy in generating all of the power required in a factory in a central station is unquestionable. The high speeds of electric motors, and the losses and difficulties in frequent stopping and starting, are objections that are being removed or surmounted as experience increases. Hence we may expect that, in the near future, the employment of shafting and gearing in extensive works will be largely displaced by the adoption of electrical transmission from a central generating plant and its utilisation where required by electric motors.

813. Journal bearings. Presented by Messrs. J. Woods and Co., 1864. M.2517.

These brass steps are lined with babbitt metal, an alloy of tin and antimony, possessing the property of creating but little friction or wear on a journal turning on it, if suitably lubricated. Such anti-

friction alloys are, however, too soft and weak to withstand the pressures experienced, and so are supported by being surrounded by gun metal except on the bearing surface.

One example is a bearing or step for a locomotive axle, and this has a curved exterior to insure equal longitudinal pressure. The other is a lined brass for a small crank-pin, which, to permit of additional freedom, is slightly spherical in form.

814. Model of shafting and supports. (Scale 1 : 15.) Presented by Capt. F. Fowke, R.E., 1859. M.1760.

This represents the ornamental standards and lattice girders used in the Paris Exhibition of 1855 for supporting the shafting for driving the machinery in motion. The girders, besides supporting the intermediate bearings, formed a gallery, by which the attendant could obtain access to all the bearings for the purposes of oiling without the use of ladders.

815. Bearings for shafting. Lent by Messrs. Croft and Perkins, 1892. M.2481.

Two systems of self-adjusting bearings are here shown. The object in both cases is to secure that the bearing shall fit the shaft uniformly over its length, and that any settling in the supports shall, by the self-adjusting arrangement, be prevented from causing serious binding. In one case the cast iron bearings in halves are each provided with a spherical projection, and the bearing is held in its bracket by two large screws with recessed heads, so that a ball and socket joint is obtained. In the other arrangement, patented by Mr. W. R. West in 1889, brasses are employed, and are carried in a plummer-block with a long cylindrical tail-piece, which is carried in a bored T-arm with a smaller tail-piece, which is again carried in the bored bracket. The complete arrangement permits of automatic adjustment by rotation round two axes at right angles, while these sliding tails, being secured by set screws, give a ready adjustment in two directions. The pulley shown is built up, having a cast iron boss and wrought iron arms and rim, but the rim is made of a section giving extra thickness in the middle where the arms are attached. It is a split pulley with a slightly tapering bore, and is secured to the shaft by a corresponding bush which is cut into three pieces, the object being to permit of the pulley being readily fitted to a shaft of a different diameter by simply substituting a fresh bush.

816. Model of roller bearing. Watt collection. Presented 1876. M.1815.

In this model a horizontal shaft carrying a fly-wheel is supported in two bearings, each having a live ring with six cylindrical rollers. The bed for the rollers is carried in a ring with a spherical exterior, so obtaining the reduction of friction due to a roller bearing, with the correct alignment of a spherical one. It is stamped "Garnett & Co., No. 1 Patent," the specification of which is dated January, 1787 (*see* No. 817).

817. Early roller bearing. Presented by the Admiralty, 1864. N.1010.

The method first adopted for minimising friction in the case of an axle or journal seems to have been by making a bearing of the peripheries of narrow wheels of comparatively large diameter. These "anti-friction wheels" were applied by Henry Sully, about 1720, to the balances of clocks.

The more generally applicable method of interposing a number of small rollers between the journal and its bearing was patented in 1787 by John Garnett of Bristol, as here shown. The rollers do not touch one another and their ends are turned down so as to take bearings in two rings, which are held apart by distance pieces riveted over, forming a "container" or cage, which is retained in the recess by a ring sprung into a groove. There is still considerable sliding friction, so that in another modification grooves were turned in the middle of the rollers, which were held in position by a washer notched to suit. This would, however, lead to "cross winding."

A manufactory was established and the bearings were made in large numbers, but these disadvantages and the unsuitability of the materials employed, coupled with the cost due to the high standard of accuracy needed, caused them to fall into disuse, except for light work such as that shown, for which they were long retained.

The sheave is 7 ins. diam., the pin ·75 in. and the six rollers ·625 in. diam. and ·875 in. long.

818. Roller bearings. Lent by the Roller Bearings Co., 1898. M.3038.

To keep the rollers parallel with the shaft, so that they shall have a distributed pressure, and also not jam themselves through travelling endwise, they are carried loosely in a cage which runs freely on the shaft and in the axle box, and has merely a controlling influence on the rollers when they are free from the bearing pressure. Such roller bearings for shafts of 1, 1·5, 2, and 3 in. diam. are shown in detail, also complete axle boxes for a railway carriage and for a tramcar fitted with these rollers. It is considered that the starting effort in vehicles so fitted is remarkably reduced, while the almost total avoidance of lubrication effects also an important economy.

819. Roller bearing. Lent by the Hyatt Roller Bearing Co., 1906. M.3470.

The rollers in these bearings are of the hollow and flexible construction patented in 1892 by Mr. J. W. Hyatt; it is unnecessary to harden and grind the surfaces in contact as the elasticity of the rollers ensures that the load shall be distributed uniformly.

They are formed of steel strip, of section proportioned to the load to be carried, coiled on a mandrel into a close helix. Usually a roller with a right-handed helix alternates with a left-handed one; it is stated that there is no end thrust.

In one case the rollers are retained in a whole cage, the ends of which are bossed inward to keep the rollers in position without constraint. This is for a shaft 1·31 in. diam. and has eight rollers ·62 in. diam. made of strip ·31 in. wide by ·12 in. thick.

The other example is a split bearing. The rollers are in loose contact with the shaft and with a steel liner split on a plane inclined to that of the diameter and contained within a swivelling sleeve with oil catchers at the ends. This is for a shaft 1·56 in. diam. and has eleven rollers ·5 in. diam. made of strip ·31 in. wide by ·06 in. thick.

820. Roller bearing. Made by Messrs. Kynoch, Limited, 1901. M.3189.

This bearing, which was patented in 1896–9 by Mr. E. Jones, possesses the same advantage as does the Hyatt roller bearing (*see* No. 819) resulting from the construction of the rollers of a hollow form possessing considerable elasticity. In this case the rollers are made from V-shaped stampings which, when coiled, form both right and left-handed helices, thus neutralising any tendency to travel and cause end thrust. The rollers are made of unequal length in order to break joint, and are threaded on rods forming a split cage by which they are retained within a bored sleeve carried in a plummer block. The example is for a 2 in. diam. shaft, and the cage, or live ring, contains fourteen rollers ·5 in. diam. made from steel ·06 in thick. A spare stamping is shown.

821. Roller bearings. Lent by Mossberg Roller Bearings, Limited, 1901. M.3187.

This method of construction was patented by Mr. F. Mossberg in 1895–8. For a cylindrical bearing an annular cage is bored longitudinally with holes of greater diameter than its thickness, the rollers are then inserted and held in place by an end cap, with projections fitting into the roller spaces and retained by a spring clip. For an end-thrust bearing, the holes and rollers are conical, and the rollers are retained in position by an outer steel ring.

822. Ball bearings. Lent by the Hoffmann Manufacturing Co., Ltd., 1906. M.3453.

Ball bearings, although proposed at the end of the 18th century received no application of any importance until about 1875, when they were adopted in cycle construction, where the loads are very small. The experience thus gained and the development of machine tools, which has enabled the component parts to be manufactured commercially with the necessary high standard of accuracy, have led to the extension of such bearings to heavy loads and speeds up to 3,000 revs. per min. Experiments have shown that for a given load the stress is considerably reduced and the compression of the ball and the race is less when the race is grooved than when it is a plane surface; it was also found that it is of the greatest practical importance that the surfaces should be highly polished.

The bearings shown embody these features and illustrate different applications; they were introduced in 1899 by Mr. E. G. Hoffmann. They comprise: (*a*) Medium type journal bearing for a shaft 2 in. diam. having a single row of nine balls ·625 in. diam. It consists of two concentric collars of hardened steel grooved and ground for the balls which are inserted between them and retained by a gunmetal cage in halves riveted together. The inner collar may be a driving

fit on the shaft or may be clamped by a nut on an interposed conica bush. The outer collar would be supported by a plummer block, etc. (*b*) Medium type thrust bearing for a shaft 2 in. diam. having a single row of ten balls ·625 in. diam. The upper collar is a driving fit on the shaft while the lower one has a conical seat so as to centre itself readily; the balls are held in a gunmetal cage and the whole is retained by a spring wire in a housing supported by a footstep, etc. (*c*) Thrust-washer for a shaft 2 in. diam. having a single row of eighteen balls ·31 in. diam. between two hardened steel washers; the balls are held in a cage as before.

823. Butler's frictional coupling. Lent by the Kirkstall Forge Co., 1890. M.2328.

This coupling, patented by Mr. H. M. Butler in 1879, consists of a muff which is placed over the two shafts, but no keys are employed. It is secured by two split tapered bushes which grip on to the shafts as they are drifted into the conically bored ends of the coupling. These bushes are driven home with their splits diametrically opposite, so that by the use of a long key drift no difficulty is experienced in driving them back if necessary. An internal nut at each end of the muff prevents the bushes from working out. The drifts and spanner used in fixing or releasing the coupling are shown, in addition to a sectional drawing.

The shafting on which these couplings are shown is known as planished shafting, and has not been turned. It is finished-rolled at a dull red heat between two discs with their faces parallel, but their axes are not in the same line. The rotation of the discs causes the shafting to rotate, while at the same time it slowly works its way between the discs, issuing in the state shown and straight enough for most purposes.

824. Flexible coupling for shafting. Lent by P. Brotherhood, Esq., 1890. M.2288.

This coupling, patented by Mr. P. Brotherhood in 1883, is designed to give a certain freedom in the connection of two revolving shafts so as to allow for any small error in their alignment, also to permit a limited amount of end play and to give some elasticity in the driving connection. A leather washer is employed to connect the two shafts, being secured at its outer circumference to the one shaft and at its inner circumference to the other through suitable flanges that are keyed on, as shown in the sectional drawing attached. One of these leather washers is exhibited which has been in use for twelve months running at 80 revs. per min. and transmitting 40 H.P.

825. Universal joint. Contributed by R. Bodmer, Esq., 1857. M.11.

This universal joint, patented by Mr. J. G. Bodmer in 1841, for enabling one shaft to drive another which is inclined to it instead of being in the same straight line, has a hollow boss on one shaft partly spherical; into this fits the end of the other shaft, which has a spherical

boss. Two loose segmental blocks with pins are let into grooves in the solid spherical boss. The pins take into holes in the hollow boss, thus communicating motion.

826. Stow's flexible shafting. Received 1890. M.2297.

This arrangement was patented by Mr. N. Stow in 1874. The shaft is shown complete with driving gear as fitted for working a portable drill. From the overhead counter-shaft the power is transmitted by a rope to the flexible shaft, a hanging double sheave block enabling large variations to be made in the virtual length of the rope according to the position of the work. When so great a range is unnecessary it is better to dispense with the hanging sheave block by running the rope directly from the counter-shaft to the flexible shaft.

The flexible shaft resembles a short length of steel wire rope, and is carried in a leather sheath with a protecting lining of wire. A spare shaft is shown withdrawn from its sheath. This shaft is intended for driving metal drills of from ·5 in. to ·625 in. diam., when its speed is about 600 revs., but when wood-boring the speed of the shaft is 1500 revs. per min. The gearing at the portable drill reduces these speeds in the ratio of 4 : 1, but when driving a portable grinding apparatus such a large reduction is not made.

827. Model of reversing gearing and friction clutches. (Scale 1 : 6.) Contributed by R. Bodmer, Esq., 1857. M.48.

This arrangement was patented in 1843 by Mr. J. G. Bodmer, as a means for winding from mines with a non-reversible motor.

Two bevel wheels mounted loosely upon the motor shaft have pinions gearing with large spur wheels fixed to each of the winding drums. A third bevel wheel gearing with the first two runs loose upon a fixed shaft, so that the winding drums rotate in opposite directions. On a sleeve on the main shaft are two friction clutches, which may engage with either of the bevel wheels, while when in the intermediate position a brake acting upon the third bevel wheel is brought into action by a weight, and locks the wheel, thus stopping the winding drums.

The friction clutches employed were patented by Mr. Bodmer in 1839, and they embody the principle of the toggle joint. Each consists of three radial arms hinged to a sleeve and carrying segments which are forced against the internal rim of its bevel wheel.

828. Model of a friction clutch. (Scale 1 : 4.) Lent by Messrs. J. Bagshaw and Sons, 1888. M.1880.

This is a form of friction clutch, patented by Mr. W. Bagshaw in 1884, for driving a single wheel or pulley. Within the large hollow boss of the wheel is a split ring of somewhat smaller diameter, which, in its normal condition, is capable of revolving within the boss without touching it. The action of a wedge and a pair of multiplying levers between the free ends of the split ring causes the latter to expand and press against the internal circumference of the boss of the wheel. The split ring is fixed at the centre of its length to the shaft, and the wedge is forced in by a hand lever.

829. Model of Napier's differential clutch. (Scale 1 : 4.) Lent by Messrs. Napier Bros., 1899. M.3055.

This friction clutch was patented in 1867 by Mr. R. B. Napier, as an improvement upon a brake patented in 1861 by Mr. R. Napier, but a still later modification of the invention has since been patented by Messrs. D. and W. Napier.

As shown in the model, there is a continuously rotated shaft upon which is secured a brake sheave, while loose on the shaft is a rope drum and a sliding collar by which the clutch can be closed or released. On the sheave is a brake strap, the two ends of which are connected with a bell-crank lever turning on a pin secured to the rope drum. The bell-crank arms are unequal, so that movement of this lever in one direction tightens the strap, and in the other direction lengthens it to an extent determined by the difference in length of the two arms. This movement of the bell-crank is controlled by two horns projecting from the sliding sleeve; these horns engage with inclined pieces, one fitted to the strap and the other to the rope drum, so that sliding the sleeve causes a relative motion of these two parts.

When the strap is tightened, any slipping action in one direction tends to increase the grip, while motion in the opposite direction releases it, so that this arrangement is only suited for driving in one way. In a modification patented in 1886 two fulcra are provided for the bell-crank, and in this way double action is obtained.

830. Coil friction clutch. Lent by the Consolidated Engineering Co., 1902. M.3217.

In this clutch, which was patented in 1893–5 by Mr. W. H. Lindsay, the closing pressure is derived from the grip of a coil which passes several times round a smooth drum and has its slack end controlled by the brake lever.

To the continuously running shaft is keyed a small drum, embraced by a helical spring of square section and of 4·5 turns, which is bored out to clear the drum freely. One end of the spring is secured to an enclosing casing to which the pulley to be driven is keyed, while the other end is attached to a lever on the end cover of the casing. Through this cover an ordinary clutch sleeve passes, the end of which is made conical, so that when forced inward it moves the lever and causes the spring to tighten on the drum. The cover of the case is secured by screws and slotted holes, by which means the clearance between the coil and drum can be adjusted.

This clutch will not drive in the wrong direction, but can be converted for driving in the opposite direction by the substitution of a left-handed spring.

831. Model of a hydraulic friction clutch. (Scale 1 : 8.) Lent by the Monkbridge Iron and Steel Co., 1887. M.1868.

This shows a clutch, patented in 1868 by Messrs. F. W. Kitson and P. Chalas, for reversing rolling-mills or other heavy machinery. Two discs mounted on one shaft revolve with it, and are capable of sliding a short distance on the shaft. Facing each disc is another disc keyed upon a hollow shaft, the hollow shafts being driven by gearing in opposite directions. Hydraulic pressure is employed to force one or

other of the sliding discs against the driving disc facing it, so as to drive by the friction between the surfaces. This is effected by forming, on the back of each of the sliding discs, a shallow hydraulic cylinder of large diameter, fitting a piston fixed upon the shaft; water under pressure is conveyed through passages bored in the central shaft, the flow being controlled by a valve.

832. Screw boss pulley. Lent by Messrs. Smith and Grace, 1890. M.2332.

This is a device, patented in 1885 by Messrs. G. E. and N. Smith, for fixing pulleys to shafting without keying. The eye of the pulley is bored and screwed conically, and fitted with a similarly screwed bush. This bush is split into three or four sections which are flexibly jointed by being cemented to a piece of emery cloth. To fix the pulley, the bush is placed on the shafting and the pulley screwed on to it till the shafting is so powerfully gripped that no keying is necessary. The pulley should be so placed on the shaft that the action of the belt tends further to tighten the bush. Spare bushes enable the same pulley to be used on shafts of different sizes.

833. Fowler's clip pulley. (Scale 1 : 4.) Presented by Messrs. John Fowler and Co. M.2907.

This shows a form of V-grooved pulley, first patented in 1859, in which the sides of the groove are formed of numerous hinged plates, which can be closed together to compensate for wear of the rope. These plates are carried upon bearings at the back, so situated that the downward pressure of the rope causes a swinging together of the plates, the leverage being such that the side pressure is much greater than that downward, so that the grip is thereby increased. Such pulleys are used for transmitting power by wire ropes, as owing to the increased grip obtained, the wire rope exerts a greater driving effort than with a simple grooved pulley.

834. Driving arrangement for wire rope (working). (Scale 1 : 4.) Lent by F. W. Scott, Esq., 1896. M.2948.

The power to be transmitted is given off by a double cylinder horizontal engine, which, by reducing gear and claw clutches, drives two four-grooved pulleys, which each carry an endless wire rope. In line with each pulley is a three-grooved pulley running loose in bearings, and the wire rope in each case returns three times over the loose pulley again on to the driving pulley, so as to obtain about four times the frictional grip that it would have if simply led on and off again as an open belt.

The model represents a plant for driving two endless ropes, for hauling to and fro along separate roads the small trucks used in mines; in such cases the engines are frequently driven by compressed air supplied from the surface. At the end of each road is a return sheave, carried in an adjustable frame, by which the stretch of the rope may be taken up. For cable tramways a similar driving arrangement is adopted, but the slack is then usually adjusted by a powerful gear that slides the return pulley in the engine room further away from the driving pulley.

835. Wire rope spears driving a mine pump. (Scale 1 : 12.) Made by T. B. Jordan, Esq., 1865. M.1412.

In this arrangement the heavy wooden spears of shaft pumps are replaced by a wire rope. This is carried over large guide pulleys placed at the top and bottom of the shaft and connected by short projecting arms with the pump plungers, which are reciprocated alternately. The top pulley may be oscillated by the usual connecting rod of the ordinary bell-cranks, or may be replaced by them. The plan has been adopted in the Hartz and in Sweden.

836. Coiled steel bands. Contributed by the Perpetual Tension Propelling Belt Co., 1881. M.1525.

These are samples of bands and cords made of coiled steel wire, intended for use in place of gut or round leather bands for driving light machinery.

837. Gearing for variable speeds. Contributed by R. Bodmer, Esq., 1857. M.12.

This is an arrangement of gearing, patented by Mr. J. G. Bodmer in 1841, for driving lathes and other machinery at varying speeds through the medium of nest-gearing. On the end of the shaft of the machine to be driven is mounted a pair of radial arms, carrying a pair of intermediate pinions, the teeth of which gear into a central pinion and also into a concentric internal toothed wheel, the latter being mounted on a hollow shaft, through which passes the shaft carrying the central pinion. By means of cone pulleys the relative speeds of the central pinion and of the internal wheel can be varied, thus varying the rate at which the intermediate pinions are carried round, and, consequently, the rate at which the machine is driven.

838. Motor car change-speed gear. Presented by the Albany Manufacturing Co., Ltd., 1906. M.3435.

This is an example of the change-speed gear designed by Mr. F. Lamplough for use on a10 H.P. petrol car. The car has a single cylinder horizontal motor with a transverse crank-shaft, and the power is transmitted to the change-speed gear, whose axis is placed longitudinally, through a cone clutch and worm gearing, and from thence by a propeller shaft to a live rear axle. The drive is direct on the high speed, but a lower speed and a reverse are provided by epicyclic gearing.

The gear box is in halves, the upper part carrying the driving worm and a separate casting enclosing it. The box contains a through shaft supported in bearings at each end, and upon the middle of this is loosely mounted the worm wheel, which has a boss of considerable length. The speed-changing gear consists of an epicyclic train, the central wheel of which is keyed to the front end of the worm wheel boss, while the internally toothed outer member runs loose and has an external flange provided with notches. The intermediate pinions are mounted on pivots fixed in the flange of a sleeve which is keyed to the shaft. Upon this sleeve is keyed by feathers a sliding collar having three projecting clutch pins which pass through the pinion flange and enter bushed holes in the outer member of the gear, so locking the worm-wheel to the shaft and producing the direct drive. On the other

side of the worm-wheel is a similar train of wheels for reversing, but in this case the outer member is fixed to the shaft, while the pinion carrying sleeve is loose, it also has a notched flange and an extra bearing surrounding it. The sliding collar is embraced by forks which are fitted to arms on a transverse shaft in the bottom of the gear box and moved by a hand lever. The forks are also connected with a pair of sliding bars fitted in grooves formed between the two parts of the gear box; these bars have projecting teeth which are so arranged as to engage alternatively with the notches in the flange of the rear wheel train, giving the reverse at half speed, or with those of the outer member of the forward train, giving the low speed which is one-third the high. When neither clutch pins or bars are engaged, the worm-wheel runs free.

The worm shaft bearing on the side next the motor is lengthened and has cut on it a quadruple screw thread; a lever fitted to this actuates the driving clutch, and its position is adjusted by rotating the bearing by means of spur gearing and an external key spindle. Ball thrust washers are provided on the worm and gear shafts. The rear end of the gear shaft carries a brake drum and finishes in a forked end for a universal joint.

839. Humpage's reduction gearing. Received 1899. M.3048.

This mechanism, patented in 1887 and 1892 by Messrs. Humpage and Jacques, is an epicyclic train of bevel wheels by which two shafts on a common axis are so connected that they run at very different speeds. Though primarily designed as a substitute for the back gearing of lathes, it has been successfully used to transmit power from a high speed electric motor to slow running machinery. In addition to the reduction that it accomplishes, it enables the machinery to be stopped or started without interfering with the running of the motor; the mechanism can also be used as a differential gear.

In the arrangement shown a pinion of twelve teeth, secured to the end of the driving shaft, engages with a wheel of forty teeth, which is carried on an arm turning loosely round the axis of the shaft. Secured to and co-axial with this wheel is a wheel of nineteen teeth, which engages with another of thirty-six teeth secured to the driven shaft. The wheel of forty teeth also engages with one of forty-eight teeth, which forms the end of an oil-tight drum-shaped gear-case, which encloses the mechanism, and, though normally stationary, is held in a clamp by which it can be readily released. When this wheel is loose no power is transmitted, but if it be held the driven shaft will make one revolution for every 13·64 made by the driver. If the wheel or its drum be independently driven a differential motion is obtained, whereby the speed of the driven shaft may be increased, diminished, or reversed.

The movement of the drum is particularly useful in the case of an alternating motor, which will not start against a load, for on releasing the drum the motor has only to turn it backward in its bearings, and when the motor has got up speed the load can be picked up gradually. To balance the pressures, the arm and its wheels are all duplicated.

840. Ross's speed-reducing gear. Lent by Messrs. R. G. Ross and Son, 1902. M.3228.

This compact form of epicyclic gearing was patented by Mr. J. M. Ross in 1896, and is used for coupling high-speed motors to machine tools, winches, etc., requiring to run at a much lower speed.

The gear is enclosed in a casing made in two parts bolted together, each of which carries a short shaft in a long gun metal bearing, the two shafts being in line. On the end of the driving shaft is a crank-pin carrying a double toothed wheel, the larger portion of which has thirty-three teeth and gears with a stationary internally-toothed ring having thirty-nine teeth, while the smaller portion has twenty-two teeth and gears with an internally-toothed wheel having twenty-six teeth which is attached to the driven shaft. When the motor shaft revolves, the crank pin carries round the double toothed wheel, which is thereby caused to rotate on its axis in the opposite direction by the fixed toothed ring; the combination of these rotations causes the driven shaft to revolve in the same direction as the motor shaft at a reduced speed, the reduction in this example being 14 : 1.

The crank-pin and wheels are counterbalanced and the casing is utilised as an oil bath.

841. Model of hydraulic accumulator. (Scale 1 : 16.) Made in the Museum Workshop, 1900. Plate XII., No. 7.
M.3135.

This represents a modern form of the accumulator invented by Lord Armstrong in 1851, and shows one of a pair used in the hydraulic power supply of Birmingham (*see* "*Engineering*," February, 1892).

The accumulator has a cast-iron cylinder, with a ram 18 in. diam. by 20 ft. stroke, and is connected with the 6 in. hydraulic mains by a 5 in. pipe. The ram is loaded to 730 lbs. per sq. in. by 84 tons of puddling-furnace cinder contained in an annular wrought-iron casing 9·8 ft. diam. by 20·24 ft. long, suspended from the cross-head by bolts, and guided by cast-iron blocks sliding between angle-irons secured to vertical timbers.

One accumulator is loaded with about 2·5 tons less than its neighbour, and its ram therefore rises first, till stopped by four long tie bars hanging from it, provided with nuts, which come into contact with heavy lugs on the cylinder. The other accumulator then rises, and, when within 3 ft. of the top of its travel, moves a tappet on a vertical rod which throws over a lever opening a bye-pass between the suction and discharge valves of the first of three hydraulic pumps. After 1·5 ft. more lift, the second pump is thrown out of action, and at 1·5 ft. higher, or the full stroke, the third pump is stopped. To guard further against over-pumping, a casting on the casing lifts a 2·5 in. relief valve, but if the motion should still continue grooves cut in the bottom of the ram come through the stuffing box and so allow water to escape. The total energy stored in the two accumulators is 3·7 H.P. hours.

The hydraulic pumps are driven by belting from three gas engines, one giving 25 and the other two 50 indicated H.P. each, at 160 revs. per min.; the exhaust is deadened by passing through iron pipes in a brick flue to the base of a chimney, 50 ft. high, where it is discharged through a series of pipes 1·5 in. diam., and 3 to 7 ft. long. The pumps are 3 in. diam. by 12 in. stroke, and 2·5 in. diam. by 10 in. stroke respectively and their crank-shaft makes 49 revs. per min.; part of the suction water is drawn through the gas engine jackets as cooling water. A 2 H.P. three-cylinder hydraulic engine is provided for starting the gas engines.

842. Diagrams relating to the distribution of hydraulic power in London. Lent by E. B. Ellington, Esq., 1891. M.2384.

The water is supplied at a guaranteed pressure of not less than 700 lbs. per sq. in.; where a considerably higher pressure is desired a hydraulic intensifier is employed by the consumer to deliver a proportionately less quantity of water at the required pressure. The intensifier represented is for delivering water at a pressure of 4,500 lbs. per sq. in. into a press for squirting lead pipe. It consists of an upper cylinder fixed on columns and fitted with a ram 15·5 in. diam. by 13 ft. stroke; at the base is fixed a ram of 6 in. diam., and upon this the upper ram, which serves also as a cylinder, can travel. By the hand valve shown, water at 700 lbs. is first admitted to the small ram, so causing the large one to rise to the top of its travel; a lever is then moved closing the supply to the small ram and admitting it to the large one, which is thus forced downward, the water within it being at the same time expelled to the lead press.

The large stop valves on the power mains are owing to the pressures involved, of the compound type shown, having a small internal valve and an equilibrium cylinder controlled by it, so that the labour of opening the large valve is reduced to that necessary for manipulating the small one. On each side of the main valve is a spring-loaded "momentum valve," by which serious concussion upon sudden closing is prevented. The arrangement consists of a plunger pressed home by a powerful spring, so adjusted that the arrested momentum of the water column is absorbed in forcing the plunger outward; after the energy has thus been stored in the spring the plunger returns it to the main.

The cast-iron mains are connected by oval flanged joints, the lugs of which were at first rather liable to be broken off, but this defect was overcome by placing them further from the end, as shown in the drawings.

843. Diagram of the Niagara Falls power plant. Presented by the Institution of Civil Engineers, 1896. M.2919.

The total available power of the Niagara Falls is about five millions H.P., an amount the generation of which, by the agency of steam, would it is estimated, absorb the whole of the world's present consumption of coal. The scheme of the Niagara Falls Power Co., however, proposes to utilise only 3 per cent. of this energy by passing one-thirtieth of the total quantity of water through turbines, directly connected with dynamos, which shall convert the power into electrical energy sufficient for all industrial work in the district.

The water taken by the portion of the scheme illustrated is conveyed to the turbines through an intake-canal, ·28 mile long, with a maximum section of 18 ft. by 17 ft. and a water depth of 12 ft., from which the supply is passed down to each turbine by a pipe 7·5 ft. diam., giving a total fall of 136 ft. After transferring its power to the turbines the dead water is conveyed by a tail race tunnel, 1·8 miles long, to the river below the falls. The diagram shows two of the turbines and dynamos, but for this portion of the installation it is intended to place ten of these turbines in a row, in one long pit cut in the solid rock.

Each turbine is of 5,000 H.P., and consists of two Fourneyron three-storied turbine wheels one above and the other below the guide casing into which the supply water is delivered. The disc of the upper wheel is perforated, while that of the lower is solid, so that there is a nearly constant resultant upward pressure counterbalancing the weight of the shaft and its attachments amounting to about 68 tons. The dynamo at the top of each shaft is of the two-phase alternating type, running at 250 revs. per min. and giving a voltage of 3,400, with a frequency of 25 per second.

APPENDIX.

The following objects were received after this volume was in the press. Their numbers, however, indicate their serial positions in the Catalogue.

105a. Parsons' steam turbine (working). Made from drawings prepared in the Museum, 1907. M.3504.

This type of compound turbine was introduced and patented by the Hon. C. A. Parsons in 1884 (*see* No. 104). The drawing shows a longitudinal section of a later and improved turbine for driving a dynamo having an output of 75 k.w., and the model represents a portion of the high pressure end of it, showing the drum, casing, and blades.

The turbine consists of a shaft or drum of varying diameter having fixed to it a number of rows of blades or vanes, which alternate with similar rows set in the opposite direction and fixed to a surrounding casing. The action differs from that of the impulse type of turbine (*see* Nos. 105 and 106), in that the steam expands in the moving rows as well as in the fixed ones, so that there is a continuous fall of pressure throughout the annular channel of increasing area formed by the blade spaces. In order to utilise the energy of the steam efficiently and at the same time to keep the velocities low, the number of blade rows must be large. The first drum of the series, however, must be small on account of the full circumferential admission necessary and the small radial clearance allowable, but by increasing the diameter of the drum towards the exhaust end, the number of blade rows is decreased and the end blades shortened. The steam enters at one end and the resulting axial thrust, which in the early machines was obviated by making the turbine double ended, is balanced by drums formed on the shaft at the high pressure end, corresponding in diameter to the several blade drums and having the same steam pressures acting upon them through passages in the casing. This reduces the length of the machine and increases its efficiency. The blades increase in size from the high pressure end downward and also the axial clearances, which are nowhere less than ·125 in. The blades are made of a special bronze, drawn in strips and cut to length; they are mounted in grooves turned in the drums and in the casing, with distance pieces between them, and

the whole caulked tight. The grooves in the drum are slightly undercut or seriated. The shaft, where it passes out of the casing, and also the balance drums, are kept steam tight by labyrinth stuffing boxes or packings. These consist of a series of projecting collars turned on the shaft or drum alternating with a similar series of rings fixed in the surrounding casing and almost in contact with them on one face but with a large clearance on the other; this causes alternate throttling and expansion of the steam and prevents appreciable leakage. The shaft stuffing boxes are connected so that steam and not air leaks into the vacuum end. The shaft bearings are quite outside the turbine casing and are made slightly elastic by surrounding the brasses with a series of concentric sleeves fitting easily into one another, oil being supplied by a pump. Axial adjustment is provided for by a small thrust block at the end of the shaft. The steam is admitted through a double-beat valve actuated by a piston above it; its movement is controlled by a slide valve attached to one end of a lever the fulcrum of which is caused to oscillate by means of another lever and a cam driven by a worm on the shaft; the other end of the valve lever is controlled by a solenoid or a centrifugal governor. The effect is that the steam is admitted in a series of puffs increasing in duration with the load until the flow becomes continuous. A runaway valve is fitted which cuts off the steam should the controlling apparatus fail.

In this machine there are three diameters of drum, forty-eight rows of moving blades, and an equal number of fixed ones varying in length from ·5 in. to 1·75 in. The shaft runs at 4,140 revs. per min., giving a minimum blade speed of 100 ft. per sec. When using saturated steam of 140 lbs. pressure and a vacuum of 27 in., it uses about 29 lbs. per k.w. hour. A larger machine, however, developing 3,200 k.w. and using superheated steam, has shown a consumption of 14·11 lbs. per k.w. hour.

562a. Feed pump (working). Made by A. G. Mumford, Esq. Received 1907. M.3498.

This is a direct acting suction and force pump for boiler feeding, etc. The flywheel, controlling the slide valve of the steam cylinder through an eccentric, is driven without the intervention of a connecting rod by a block on the crank pin sliding in a slot at right angles to its length in the common piston rod which thus has a simple harmonic motion. The suction and delivery valves are of the mushroom type. The steam cylinder is 2 in. diam. and the plunger 1·2 in. diam. with a common stroke of 1·9 in.

572a. Model of Riedler pump. (Scale 1:16). Lent by Messrs. Fraser & Chalmers, Ltd., 1907. M.3475.

The feature of this pump, which is of the differential plunger type, is that the valves are operated by mechanical means. This enables the pump to be worked at a higher piston speed than if the valves were moved, as is usual, by the liquid passing through them; it also minimizes concussion and obviates "slip." The arrangement is that patented in 1885 to 1891 by Professor A. Riedler.

The valves are of the annular type and have a high lift. They open freely with the help of springs, etc., but are closed, just as the end of the stroke is reached, by bent levers interconnected by an external rod, and actuated by a rod and eccentric on the crank shaft or by other means. To obviate the breakage that might result from inaccurate adjustment, the valve is made in two parts on a tubular spindle with a spring interposed so that a slight movement may take place after the valve has reached its seat.

The area of the outer end of the plunger is twice that of the inner end. When the plunger moves to the left the suction valve is closed and the delivery valve opens and through it passes the full volume displaced. Half of this goes to the delivery main and the other half is drawn into the space left by the stroke substituting the large for the small part of the plunger in a chamber enclosing it. In the return stroke this latter half is displaced to the delivery main while a fresh quantity is being drawn in. Thus the advantages of a double acting pump are obtained with only two valves.

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